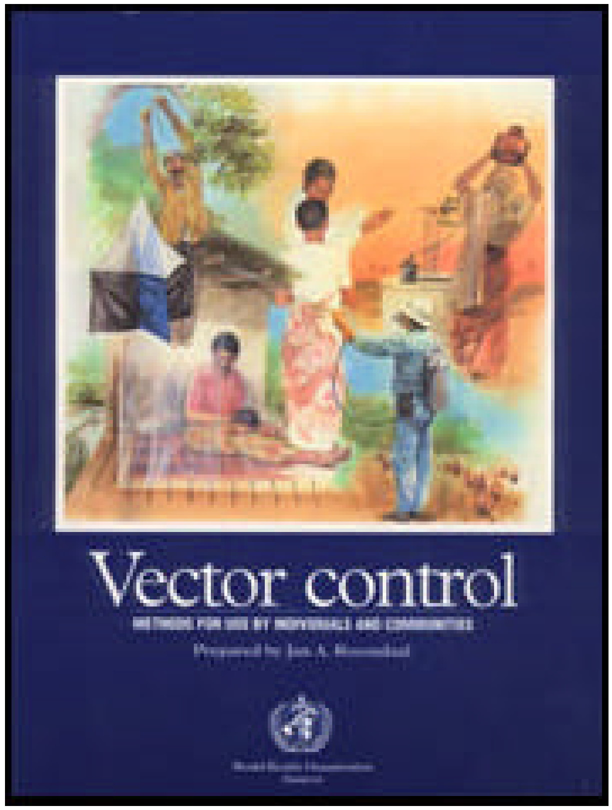

Vector Control - Methods for Use by Individuals and Communities

ISBN 92 4 154494 5

Prepared by Jan A. Rozendaal

World Health Organization
Geneva
1997

The World Health Organization was established in 1948 as a specialized agency of the United Nations serving as the directing and coordinating authority for international health matters and public health. One of WHO's constitutional functions is to provide objective and reliable information and advice in the field of human health, a responsibility that it fultils in part through its extensive programme of publications.

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Foreword

The development and production of this manual have been an enormous task. Relevant information has been assembled on the control of disease vectors, reservoir species and household pests with the specific objective of providing practical guidance to non-professionals. The target species addressed in this book and the control methods described have been selected for an audience of individuals and communities whose potential contribution to vector control is considerable, but may be restricted by factors such as lack of financial resources and limited education. The decision-making structure of the community and control activities undertaken by local health services are also important in determining which control methods are appropriate.

Most of the research, data collection and field visits needed for this book were carried out by Dr Jan A. Rozendaal between 1988 and 1991. The resulting draft manuscript was then reviewed by various specialists in vector-borne disease control, who made a number of suggestions for changes to the text. In preparing the final manuscript, Dr Rozendaal has incorporated information on new developments in vector control to ensure that the text is as up to date as possible.

This book is particularly timely, since it appears as vector control is coming to depend less on large-scale control programmes organized by governments and more on community participation at the local level. In addition, it is now clear that many of the traditional methods used to prevent and control vector-borne and other infectious diseases are either incorrectly applied or no longer effective. Under the combined pressures of economic development, environmental and demographic changes, and increasing human migration, diseases are reappearing in new environments or are re-emerging in more virulent forms. Many of the agents of these diseases have become resistant to commonly used drugs or their vectors have developed resistance to pesticides. The methods described in this book, especially those directed at permanent modifications of housing and other components of the living environment, will help to prevent and control these diseases, which hinder economic progress and affect the well-being of populations in many parts of the world.

Dr K. Behbehani
Director, Division of Control of Tropical Diseases

Preface

Diseases transmitted by arthropods and freshwater snails are among the major causes of illness and death in many tropical and subtropical countries, and to a lesser extent, in temperate zones also. In addition to the toll they exact in terms of premature death and disability, such diseases - which include malaria, filariasis, leishmaniasis, schistosomiasis, dengue and trypanosomiasis - represent a significant impediment to economic development, as a result of lost working hours, and the high costs of treating the sick and controlling the vectors of disease.

Large-scale campaigns for vector control are often unworkable for both financial and practical reasons, as well as being damaging to the environment. For these reasons, attention has shifted to methods that can be applied by individuals and communities to protect themselves from vector-borne disease. Unfortunately there is little widely available information to guide non-specialists in vector control techniques. This book attempts to fill that gap, by describing methods that are suitable for self-protection by individuals and communities and that require only limited involvement by the health services in planning and community education. In general these techniques are relatively simple and cheap, do not require much training and, if properly applied, are safe for the user and the environment.

The manual includes practical information on all major disease vectors and pests, only some of which will be relevant in any particular community. The manual is therefore intended for adaptation to the local situation or to special target groups, such as travellers. The World Health Organization would welcome feedback from readers, particularly regarding use of this manual in the field. Comments and suggestions for improvement should be sent to Division of Control of Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland.

Acknowledgements

The production of this manual was made possible by the support and contributions of a number of individuals.

Dr J.A. Rozendaal, Associate Professional Officer, former Division of Vector Biology and Control, WHO, carried out most of the research, data collection and field visits needed for the book and prepared the manuscript.

Dr R. Slooff, Director, former Division of Vector Biology and Control, WHO, and Dr C.F. Curtis, Department of Entomology, London School of Hygiene and Tropical Medicine, reviewed the text and provided comments on its content and structure.

WHO gives special thanks to the experts named below for their valuable contributions to individual chapters.

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Introduction

History and background of vector control

At the end of the nineteenth century, it was discovered that certain species of insects, other arthropods and freshwater snails were responsible for the transmission of some important diseases. Since effective vaccines or drugs were not always available for the prevention or treatment of these diseases, control of transmission often had to rely mainly on control of the vector. Early control programmes included the screening of houses, the use of mosquito nets, the drainage or filling of swamps and other water bodies used by insects for breeding, and the application of oil or Paris green to breeding places.

The discovery of the insecticide dichlorodiphenyltrichloroethane (DDT) in the 1940s was a major breakthrough in the control of vector-borne diseases. The insecticide was highly effective for killing indoor-resting mosquitos when it was sprayed on the walls of houses. Moreover, it was cheap to produce and remained active over a period of many months. DDT also appeared to be effective and economical in the control of other biting flies and midges and of infestations with fleas, lice, bedbugs and triatomine bugs.

In the 1950s and early 1960s, programmes were organized in many countries which attempted to control or eradicate the most important vector-borne diseases (malaria, Chagas disease and leishmaniasis) by the large-scale application of DDT. Because of their high costs, these programmes were generally planned for limited periods of time. The objective was to eradicate the diseases or to reduce transmission to such a low level that control could be maintained through the general health care facilities without the need for additional control measures.

Initially these programmes were largely successful and in some countries it proved possible to interrupt or reduce the vector control activities. However, in most countries, success was short-lived; often the vectors developed resistance to the pesticides in use, creating a need for new, more expensive chemicals. Suspension of control programmes eventually led to a return to significant levels of disease transmission. Permanent successes were mostly obtained where the environment was changed in such a way that the vector was prevented from breeding or resting.

Alternatives to the use of insecticides

Interest in alternatives to the use of insecticides, such as environmental management and biological control, has been revived because of increasing resistance to the commonly used insecticides among important vector species and because of concerns about the effects of DDT and certain other insecticides on the environment.

Environmental management involves altering the breeding sites of the vectors, for instance by filling ponds and marshes on a permanent basis or by repeatedly removing vegetation from ponds and canals and cleaning premises.

Biological control is the use of living organisms or their products to control vector and pest insects. The organisms used include viruses, bacteria, protozoa, fungi, plants, parasitic worms, predatory mosquitos and fish. The aim is generally to kill larvae without polluting the environment. Biological control often works best when used in combination with environmental management.

Reorganization of vector control

In parallel with the investigation of alternative methods of control, attempts have been made in many countries to reorganize the delivery of services. Where possible, programmes for the control of vector-borne diseases have been decentralized and integrated with the basic and district health services. This is intended to improve the sustainability of control programmes while allowing substantial savings in financial input and in staff costs. District and village health workers have assumed more responsibility.

In the past decade, much emphasis has been given to adapting existing vector control techniques and developing new methods to enable general health personnel, communities and individuals to take action in defence of their own health. Priority has been given to the development of simple, safe, appropriate and inexpensive measures for vector control. Insecticide-treated nets and curtains have been developed for the control of mosquitos and sandflies. Traps have been developed to control tsetse flies in Africa. House design and construction methods have been modified to control triatomine bugs in South America. Special water filters have been developed to eliminate the cyclops vectors of guinea worm from drinking-water. New irrigation techniques prevent mosquitos and snails from breeding but do not damage crops.

Vector control at community level

The particular vector control methods to be applied in a community will depend on the local situation and the preferences of the population. It is essential that communities are well informed about the options available, and that they participate actively in choosing and implementing vector control activities that are appropriate to their circumstances.

Vector control methods suitable for community involvement should:

- be effective;
- be affordable;
- use equipment and materials that can be obtained locally;
- be simple to understand and apply;
- be acceptable and compatible with local customs, attitudes and beliefs;
- be safe to the user and the environment.

Methods that are suitable in one place are not necessarily so elsewhere, even if the characteristics of the disease and its vector are unchanged. Thus insecticide spraying of walls may be the preferred method for controlling malaria in one area while the use of insecticide-treated mosquito nets or environmental management may be more appropriate in another.

The important differences between the various methods are related to the type and amount of involvement required from community members, village and district health workers, and vector control specialists. The choice of method will often depend on the availability of funds and trained personnel, the level of economic and social development of the community or area, and the level of development of local health services.

Selecting the appropriate control measures

In selecting appropriate control measures, it is generally possible to distinguish two types of situation requiring different solutions:

- nuisance caused by pests;
- diseases carried by bloodsucking insects and other vectors.

In both cases, solutions can be found in the protection of individuals and the protection of communities.

It is important to distinguish between measures offering adequate protection from disease and ones that are not sufficient on their own but are of value in conjunction with other measures.

Before starting any vector control activity, it is important to ask two questions:

- What result do you want to achieve: merely to protect yourself or your family from biting pests and the diseases they carry, or to reduce disease in the community?

- Are the health authorities already carrying out control measures and do you want to provide the community or your family with additional protection from disease?

Answering these questions is essential for the selection of the most appropriate control measures. For the correct diagnosis of a disease or identification of a vector or pest species, you may need to consult local health workers who should preferably also be involved in discussions about the need for and possibilities of control. People with experience in the control of agricultural pests may be of help.

This manual provides background information that will help you to identify the vectors and diseases of importance in your community. Each chapter is divided into three sections. The first section, on biology, should enable you to confirm the groups of arthropods to which the pests and vectors belong. It also provides background information indicating what to expect from specific control measures. The second section, on public health importance, briefly reviews the diseases transmitted. For each disease, the place of vector control measures in strategies for disease control is described. Finally, practical information is given on a variety of control measures. The most detailed information concerns methods suitable for self-protection and community participation. Methods that have to be implemented by specially trained personnel are presented with minimum technical detail.

Self-protection

Self-protection measures are used to protect yourself, your family or a small group of people living or working together from insect pests or vectors of disease. These measures include personal protection, i.e., the prevention of contact between the human body and the disease vector, and environmental measures to prevent pests and vectors from entering, finding shelter in, or breeding in or around your house. These measures are usually simple and inexpensive, and can often be adopted without help from specialized health workers.

Community control

It is more difficult to protect a whole community from a vector-borne disease or major pest. The type of control may be the same as for the protection of an individual or a family, but is, of course, larger. A considerable effort is required in order to obtain the active participation of all members of the community.

Before investing resources in community-wide control efforts, advice should be obtained from health workers on the type of measures most likely to be successful under local conditions. Many factors need to be taken into account: the vector species and its behaviour, the compatibility of control methods with the local culture, affordability in the long term, the need for expert advice, etc. In certain circumstances it is more cost-effective to improve the detection and treatment of sick people than to undertake vector control measures. On the other hand if the diagnosis of a disease is difficult or if adequate treatment is not available, vector control offers the only prospect of controlling the disease.

After studying a particular situation, the community can use this manual to select the most suitable control measures; this selection should be based not only on the effectiveness of particular measures but also on their sustainability and affordability. It is also important to consider the type and amount of support local health services can provide on a sustainable basis.

Input required from health services and communities for different types of control measures

Community input		*Health service input*
high ↑	Simple, inexpensive self-protection methods, requiring the active participation of the whole community. Examples: impregnated bednets, house improvement, prevention of breeding in and around houses.	↓ low
	Technically simple methods to prevent breeding in the field, requiring active participation of some members of the community under direct guidance of trained personnel. Examples: source reduction, larvivorous fish, larvicides.	
	Methods requiring equipment, trained personnel, and financial and technical involvement of the community. Example: insecticide spraying of house walls.	
	Methods for the eradication of diseases or their vectors, requiring high investment for a limited period by the health service under the guidance of vector control experts. Examples: Onchocerciasis Control Programme in West Africa, malaria eradication programmes during the 1960s and 1970s.	
low	Emergency control methods, requiring intense action by health services assisted by vector control experts. Examples: Ultra-low-volume spraying (fogging) with insecticides to control epidemics of dengue.	high

Chapter 1 - Mosquitos and other biting Diptera

Vectors of malaria, leishmaniasis, filariasis, onchocerciasis, dengue, yellow fever and other diseases

Biology

The biting Diptera are two-winged flying insects that suck blood from humans and animals. In many parts of the world their biting is a considerable nuisance. More importantly, they are carriers of a number of diseases, mostly in the tropics, causing illness and death on a large scale.

The most important group of biting Diptera is the mosquitos, which have a long, slender body and long, needle-shaped, piercing mouthparts. Others include the blackflies, phlebotomine sandflies, tsetse flies, biting midges, horseflies (tabanids) and stable flies, which generally have shorter biting mouthparts and more robust bodies. The last three groups are of limited importance as vectors of human disease.

Table 1.1 shows the diseases transmitted by each group.

Distinguishing features of biting Diptera

Mosquitos

Mosquitos differ from the other biting Diptera in having a long slender body, long legs and long needle-shaped mouthparts (Fig. 1.1a). The wings sometimes have discernible patterns of scales. The adult insects measure between 2 mm and 12.5 mm in length.

Some species bite in the morning or evening and at night; others feed during the day. Species may bite indoors or out of doors.

Table 1.1 Diseases transmitted by mosquitos and other biting Diptera

Vectors	Diseases
Mosquitos (Culicidae)	
Anopheles	Malaria, lymphatic filariasis
Culex	Lymphatic filariasis, Japanese encephalitis, other viral diseases
Aedes	Yellow fever, dengue, dengue haemorrhagic fever, other viral diseases, lymphatic filariasis
Mansonia	Lymphatic filariasis
Other biting Diptera	
Tsetse flies (*Glossina*)	African sleeping sickness
Blackflies (*Simulium*)	River blindness (onchocerciasis), mansonellosis (usually symptomless)
Sandflies (*Phlebotomus*, *Lutzomyia*)	Leishmaniasis, sandfly fever

Horseflies (Tabanidae)	Loiasis, tularaemia
Biting midges (Ceratopogonidae)	Mansonellosis (usually symptomless)

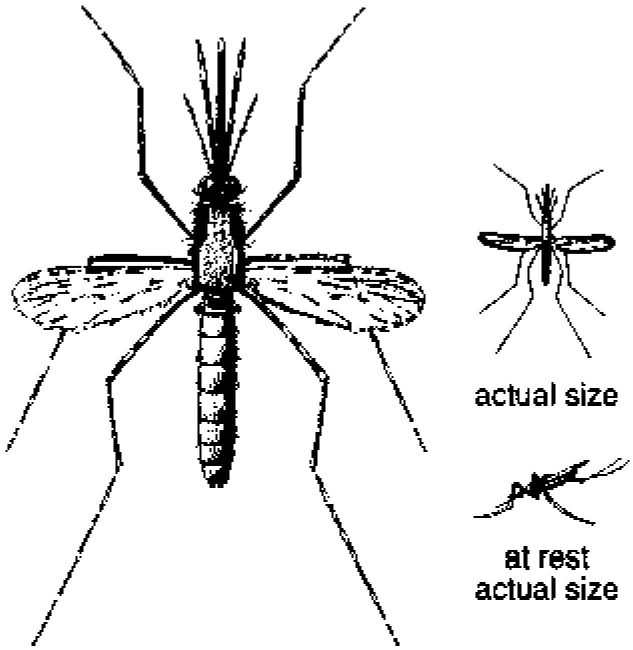


Fig. 1.1.(a) The biting Diptera - mosquitos (by courtesy of Professor M. Wéry, Institute of Tropical Medicine, Antwerp, Belgium; mosquito at rest, © L. Robertson);

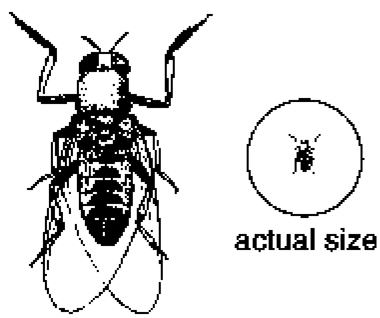


Fig. 1.1.(b) The biting Diptera - blackflies;

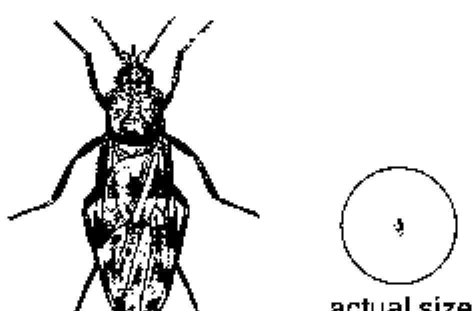


Fig. 1.1.(c) The biting Diptera - biting midges;

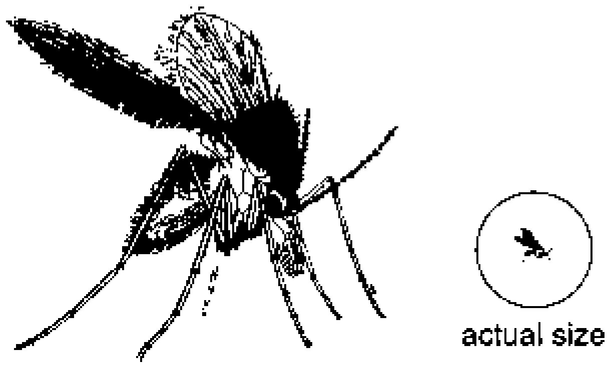


Fig. 1.1.(d) The biting Diptera - phlebotomine sandflies;

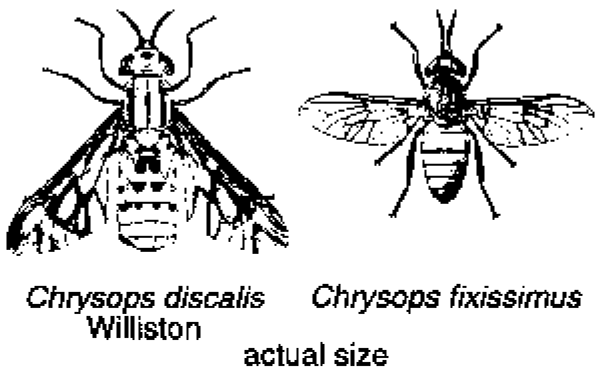


Fig. 1.1.(e) The biting Diptera - deerflies (*1*) and horseflies;

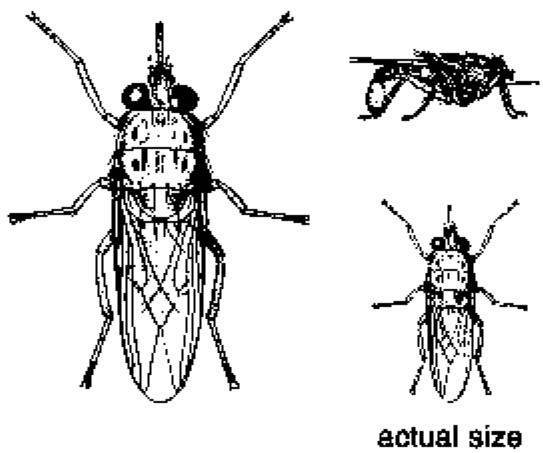


Fig. 1.1.(f) The biting Diptera - tsetse flies;

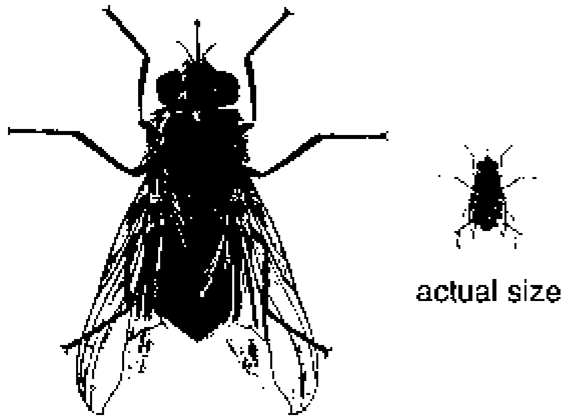


Fig. 1.1.(g) The biting Diptera - stable flies (all figures by courtesy of the Natural History Museum, London, except where otherwise indicated).

Blackflies

Blackflies are stout-bodied, about 1 - 5 mm long, and are usually black, although orange and yellow species exist. They have relatively large eyes. The legs are short, and the wings are short, broad and colourless (Fig. 1.1b).

Blackflies bite in daytime, out of doors; some species prefer to feed only on certain parts of the body, for example the legs or the upper part of the body.

Biting midges

Biting midges are about 1.5 mm long. They bite at any time of day or night, but most commonly in the late afternoon and the early part of the night. Because of their short mouthparts (Fig. 1.1c) they are not very successful in biting through clothing; they are often observed in swarms around the head, biting the face. Other exposed parts of the body may also be attacked. Most species only feed out of doors. They can be a severe nuisance and because of their small size they can easily pass through standard mesh mosquito nets.

Phlebotomine sandflies

Sandflies are about 1.5 - 4 mm long. They have a hairy appearance, conspicuous black eyes and long, stilt-like legs (Fig. 1.1d). They have a characteristic hopping flight with many short flights and landings. In contrast to all other biting Diptera, the wings are held erect over the body when at rest. Sandflies usually bite after dark, but may bite in daytime during cloudy weather in forests. Most species feed outdoors but a few feed indoors. Because of their short mouthparts they cannot bite through clothing.

Horseflies and deerflies

The tabanids are medium- to large-sized flies (6 - 25 mm long) and are avid bloodsuckers and powerful fliers. Some species are the largest biting Diptera, having a wing span of 6.5 cm. They vary in colour from very dark to light and are often iridescent. They have a large head with large conspicuous eyes. The mouth-parts do not point forward (as in the tsetse flies) but downward (Fig. 1.1e). The tabanids are especially active in daytime, in bright sunshine. They usually feed outdoors, mostly in woods and forests. Their bites are deep and painful and the wounds often continue to bleed after the flies have left. They can easily bite through clothing.

Tsetse flies

Tsetse flies occur only in tropical Africa. They are yellowish or dark brown, medium-sized flies, 6 - 15 mm in length. They can be distinguished from other large biting Diptera by their forward-pointing mouthparts (Fig. 1.1f; see also stable flies). They bite only in daytime.

Stable flies

Stable flies are dark, medium-sized flies, 5 - 6 mm in length, resembling houseflies in shape and size. They can be distinguished from houseflies and other similar-looking flies by their forward-pointing mouthparts (Fig. 1.1g). In Africa, they can be distinguished from tsetse flies, which also have forward-pointing mouthparts, by their smaller size and the position of the wings, which do not overlap when at rest. Stable flies bite in daytime and mostly outdoors. Biting is most common near farms and other places where large domestic animals are kept. The flies feed mostly on the legs.

Mosquitos

Mosquitos are important vectors of several tropical diseases, including malaria, filariases, and numerous viral diseases, such as dengue, Japanese encephalitis and yellow fever. In countries with a temperate climate they are more important as nuisance pests than as vectors.

There are about 3000 species of mosquito, of which about 100 are vectors of human diseases. Control measures are generally directed against only one or a few of the most important species and can be aimed at the adults or the larvae.

Life cycle

Mosquitos have four distinct stages in their life cycle: egg, larva, pupa and adult (Fig. 1.2). The females usually mate only once but produce eggs at intervals throughout their life. In order to be able to do so most female mosquitos require a blood-meal (Fig. 1.3). Males do not suck blood but feed on plant juices. The digestion of a blood-meal and the simultaneous development of eggs takes 2 - 3 days in the tropics but longer in temperate zones. The gravid females search for suitable places to deposit their eggs, after which another blood-meal is taken and another batch of eggs is laid. This process is repeated until the mosquito dies.

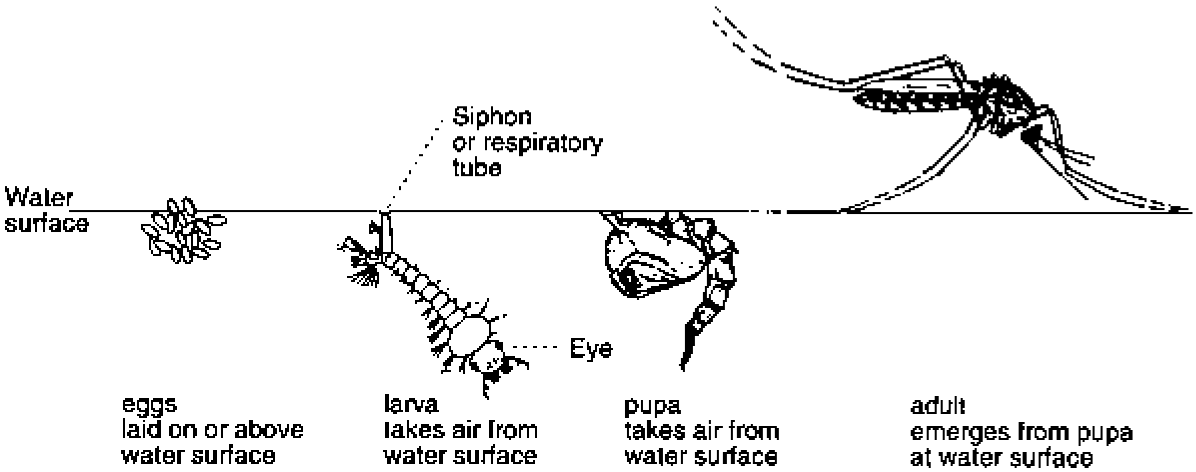


Fig. 1.2. The life cycle of the mosquito (© WHO).

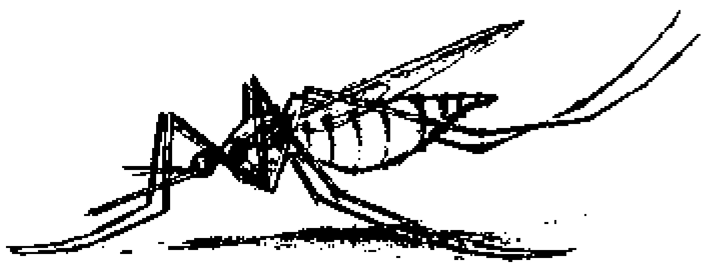


Fig. 1.3. Freshly blood-fed mosquitos have a dilated abdomen.

Depending on the species, a female lays between 30 and 300 eggs at a time. Many species lay their eggs directly on the surface of water, either singly (*Anopheles*) or stuck together in floating rafts (e.g. *Culex*). In the tropics, the eggs usually hatch within 2 - 3 days. Some species (e.g. *Aedes*) lay their eggs just above the water line or on wet mud; these eggs hatch only when flooded with water. If left dry they can remain viable for many weeks.

Once hatched, the larvae do not grow continuously but in four different stages (instars). The first instar measures about 1.5 mm in length, the fourth about 8 - 10 mm. Although they have no legs, they have a well developed head and body covered with hairs, and swim with sweeping movements of the body. They feed on yeasts, bacteria and small aquatic organisms. Most mosquito larvae have a siphon located at the tip of the abdomen through which air is taken in and come to the water surface to breathe; they dive to the bottom for short periods in order to feed or escape danger. *Anopheles* larvae, which feed and breathe horizontally at the surface, have a rudimentary siphon. Larvae of *Mansonia* do not need to come to the surface to breathe, since they can obtain air by inserting the siphon into a water plant, to which they remain attached for most of the time.

In warm climates, the larval period lasts about 4 - 7 days, or longer if there is a shortage of food. The fully grown larva then changes into a comma-shaped pupa, which does not feed and spends most of its time at the water surface. If disturbed it dives swiftly to the bottom. When mature, the pupal skin splits at one end and a fully developed adult mosquito emerges. In the tropics the pupal period lasts 1 - 3 days. The entire period from egg to adult takes about 7 - 13 days under good conditions.

Biting behaviour

Female mosquitos feed on animals and humans. Most species show a preference for certain animals or for humans. They are attracted by the body odours, carbon dioxide and heat emitted from the animal or person. Some species prefer biting at certain hours, for example at dusk and dawn or in the middle of the night. Feeding usually takes place during the night but daytime biting also occurs. Some species prefer to feed in forests, some outside of houses, others indoors.

Because digestion of the blood-meal and development of the eggs takes several days, a blood-fed mosquito looks for a safe resting place that is shaded and offers protection from desiccation. Some species prefer to rest in houses or cattle sheds, while others prefer to rest outdoors, on vegetation or at other natural sites. Mosquitos do not usually bite while eggs are developing.

The behaviour of mosquitos determines whether they are important as nuisance insects or vectors of disease, and governs the selection of control methods. Species that prefer to feed on animals are usually not very effective

in transmitting diseases from person to person. Those that bite in the early evening may be more difficult to avoid than species that feed at night. Mosquitos that rest indoors are the easiest to control.

Distinguishing features of vector mosquitos

Among the mosquitos there are two groups that suck human blood and may transmit disease.

- The anophelines; the genus *Anopheles* is best known for its role in transmitting malaria, but in some areas it can also transmit filariasis.

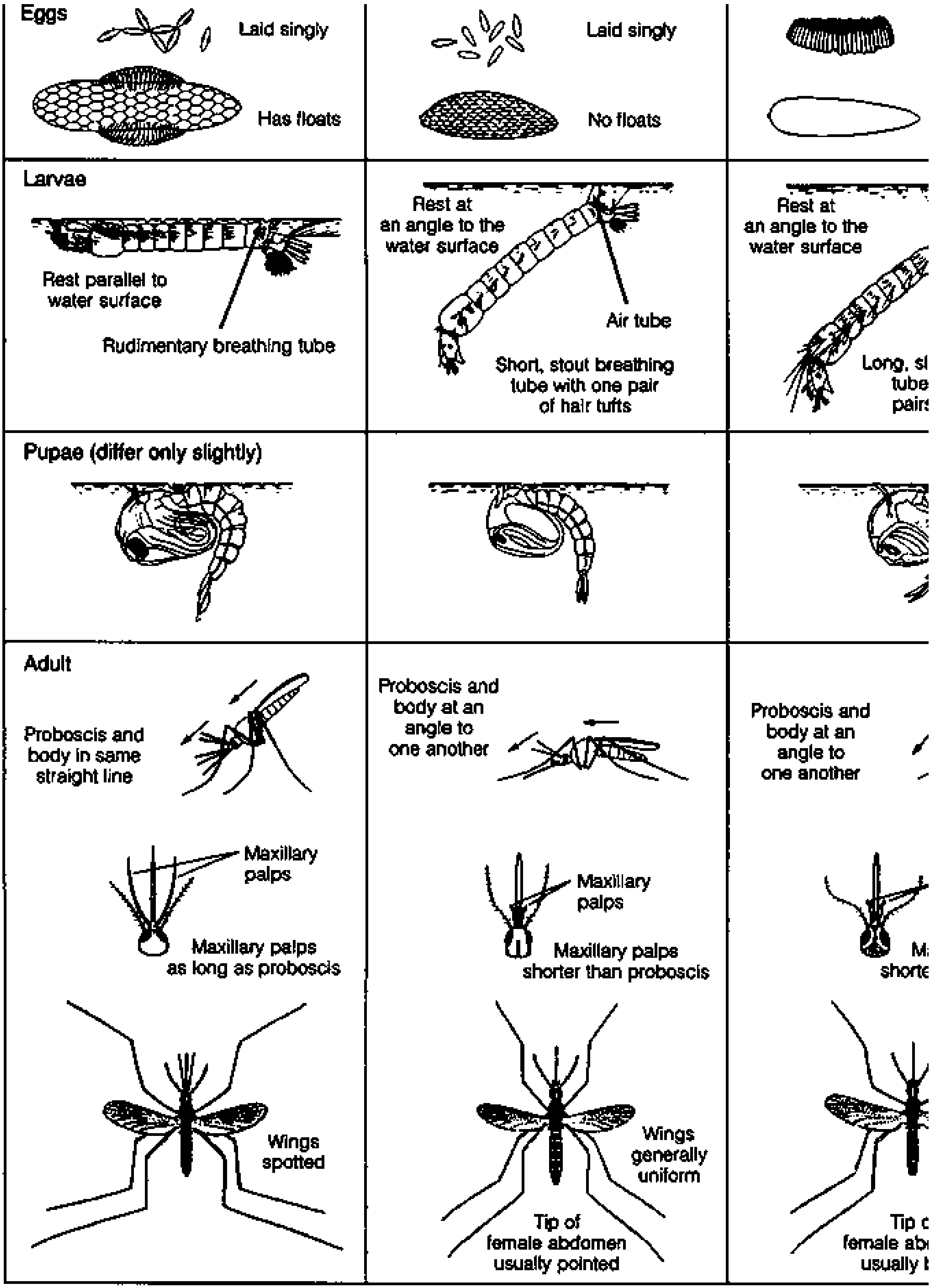
- The culicines, which include the following genera:

- *Culex*: vectors of filariasis and some viral diseases;

- *Aedes*: vectors of dengue, yellow fever and other viral diseases, and sometimes of filariasis;

- *Mansonia*: vectors of brugian filariasis;

- *Haemagogus* and *Sabethes*: vectors of yellow fever in the forests of South and Central America.



Eggs
Laid singly
Has floats
Laid singly
No floats
Larvae
Rest parallel to water surface
Rudimentary breathing tube
Rest at an angle to the water surface
Air tube
Short, stout breathing tube with one pair of hair tufts
Rest at an angle to the water surface
Pupae (differ only slightly)
Adult
Proboscis and body in same straight line
Maxillary palps
Maxillary palps as long as proboscis
Wings spotted
Proboscis and body at an angle to one another
Maxillary palps
Maxillary palps shorter than proboscis
Wings generally uniform
Tip of female abdomen usually pointed
Proboscis and body at an angle to one another

Fig. 1.4. Some of the main characteristics for differentiating *Anopheles*, *Aedes* and *Culex* mosquitos (© WHO).

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Anopheles, *Culex* and *Aedes* mosquitos can be distinguished from each other as shown in Fig. 1.4. The most useful characteristics for distinguishing anophelines from other mosquitos are:

- the length of the palps is equal to that of the proboscis;

- while at rest they usually keep their mouthparts and abdomen in a straight line at an angle to the resting surface; the angle varies with the species and in some cases is almost perpendicular to the surface. *Anopheles culicifacies*, a malaria vector in south Asia, is an exception, keeping its body almost parallel to the surface. As its name suggests, it looks superficially like a *Culex* mosquito.

Anopheles mosquitos

About 380 species of *Anopheles* (Fig. 1.5) occur around the world. Some 60 species are sufficiently attracted to humans to act as vectors of malaria. A number of *Anopheles* species are also vectors of filariasis and viral diseases.

Life cycle

Larval habitats vary from species to species, but are frequently exposed to sunlight and commonly found in association with emergent vegetation, such as grass or mats of floating vegetation or algae. The most preferred breeding sites are pools, seepages, quiet places in slow-running streams, rice fields, leaf axils of certain epiphytic plants and puddles of rainwater. Artificial containers, such as pots, tubs, cisterns and overhead tanks are not usually suitable, except in the case of *Anopheles stephensi* in south-west Asia.

The eggs, laid singly on the water surface where they float until hatching, are elongated, have a pair of lateral floats, and are about 1 mm in length. Hatching occurs in 2 - 3 days. The larvae float in a horizontal position at the surface, where they feed on small organic particles. In the tropics the duration of development from egg to adult is 11 - 13 days.

Behaviour

Anopheles mosquitos are active between sunset and sunrise. Each species has specific peak biting hours, and there are also variations in their preference for biting indoors or outdoors.

The anophelines that enter houses to feed often rest indoors for a few hours after feeding. They may then leave for outdoor sheltered resting sites, among them vegetation, rodent burrows, cracks and crevices in trees or in the ground, caves and the undersides of bridges. Alternatively, they may stay indoors for the whole period needed to digest the blood-meal and produce eggs. Indoor resting is most common in dry or windy areas where safe outdoor resting sites are scarce. Once the eggs are fully developed the gravid mosquitos leave their resting sites and try to find a suitable breeding habitat.

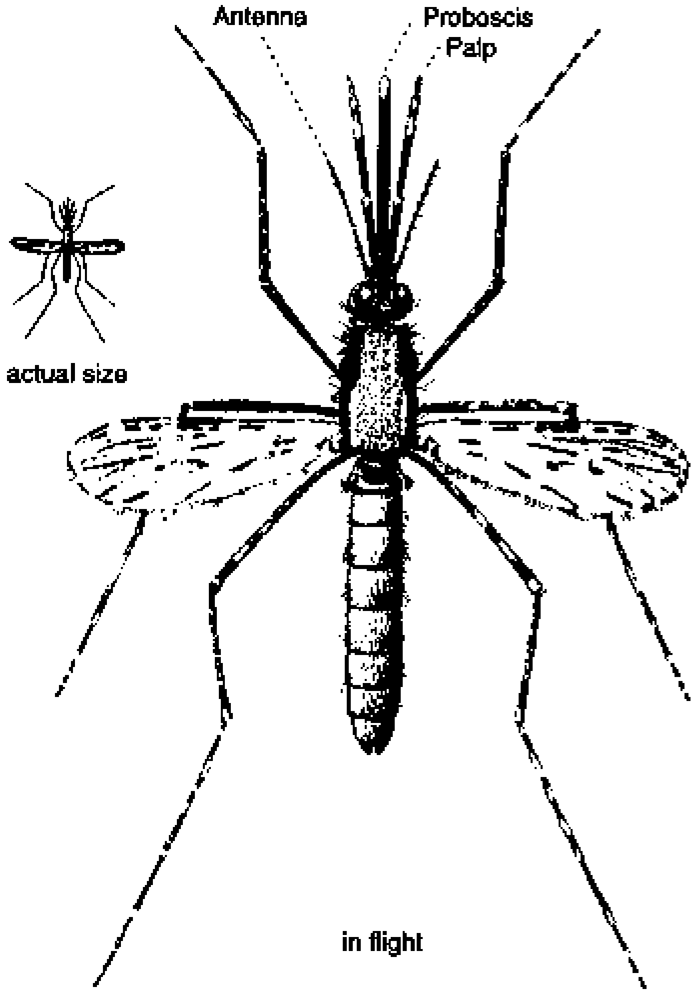

Fig. 1.5.(a) An *Anopheles* mosquito in flight (by courtesy of Professor M. Wéry, Institute of Tropical Medicine, Antwerp, Belgium);

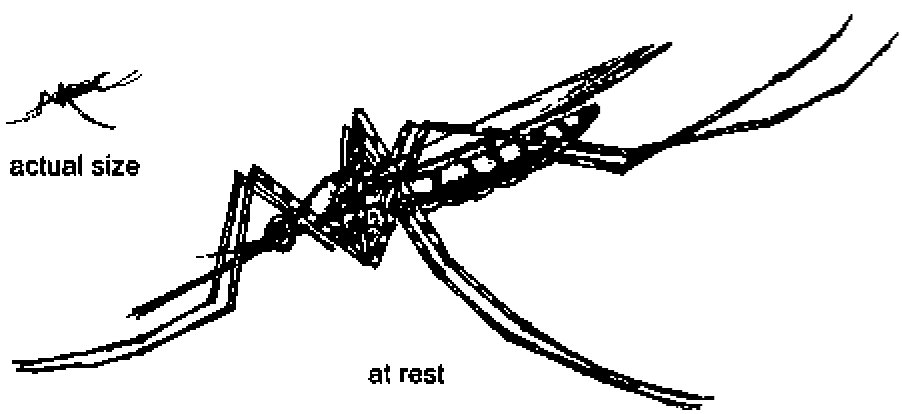

Fig. 1.5.(b) An *Anopheles* mosquito at rest (© L. Robertson).

Many *Anopheles* species feed on both humans and animals. They differ, however, in the degree to which they prefer one over the other. Some species feed mostly on animals while others feed almost entirely on humans. The latter species are the more dangerous as vectors of malaria.

Culex mosquitos

About 550 species of *Culex* (Fig. 1.6) have been described, most of them from tropical and subtropical regions. Some species are important as vectors of bancroftian filariasis and arboviral diseases, such as Japanese encephalitis. In some areas they are a considerable nuisance

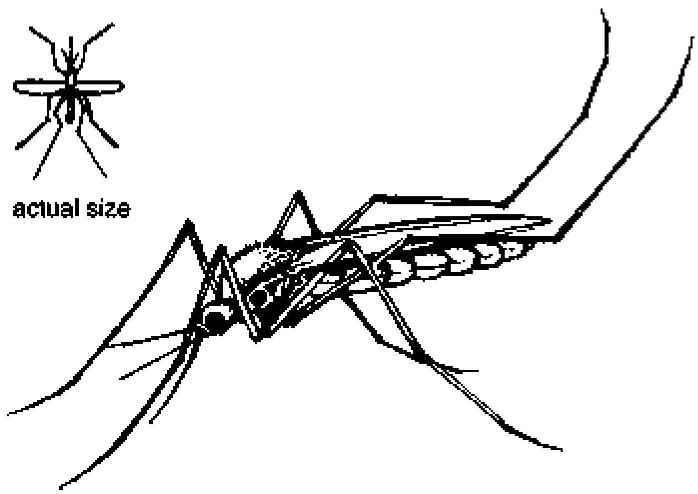

Fig. 1.6. A *Culex* mosquito..

Life cycle

Rafts of 100 or more eggs are laid on the water surface. The rafts remain afloat until hatching occurs 2 - 3 days later. *Culex* species breed in a large variety of still waters, ranging from artificial containers and catchment basins of drainage systems to large bodies of permanent water. The most common species, *Culex quinquefasciatus*, a major nuisance and vector of bancroftian filariasis, breeds especially in water polluted with organic material, such as refuse and excreta or rotting plants. Examples of such breeding sites are soakaway pits, septic tanks, pit latrines, blocked drains, canals and abandoned wells. In many developing countries *Culex quinquefasciatus* is common in rapidly expanding urban areas where drainage and sanitation are inadequate.

Culex tritaeniorhynchus, the vector of Japanese encephalitis in Asia, prefers cleaner water. It is most commonly found in irrigated rice fields and in ditches.

Behaviour

Culex quinquefasciatus is a markedly domestic species. The adult females bite people and animals throughout the night, indoors and outdoors. During the day they are inactive and are often found resting in dark corners of rooms, shelters and culverts. They also rest outdoors on vegetation and in holes in trees in forested areas.

Aedes mosquitos

Aedes mosquitos occur around the world and there are over 950 species. They can cause a serious biting nuisance to people and animals, both in the tropics and in cooler climates. In tropical countries *Aedes aegypti* (Fig. 1.7) is an important vector of dengue, dengue haemorrhagic fever, yellow fever and other viral diseases. A closely related species, *Aedes albopictus*, can also transmit dengue. In some areas *Aedes* species transmit filariasis.

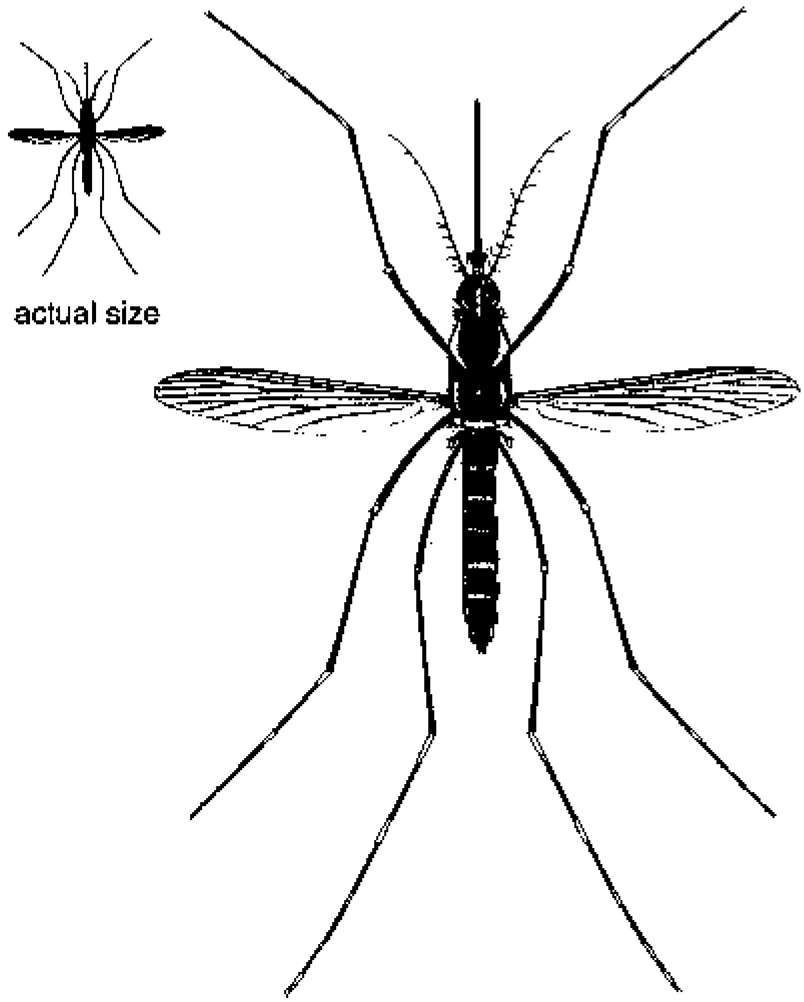

Fig. 1.7.(a) *Aedes aegypti* in flight (by courtesy of the Natural History Museum, London) and

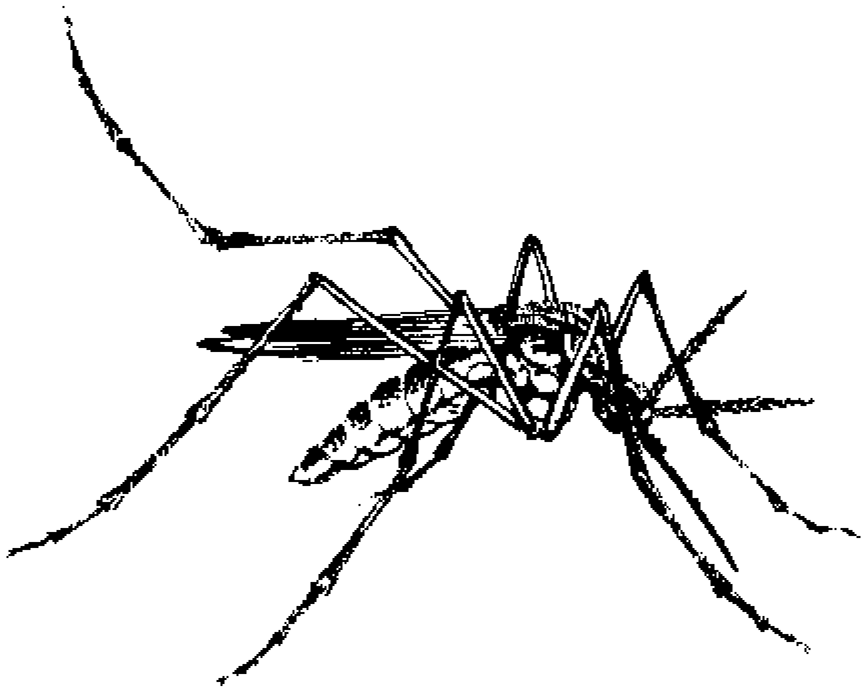

Fig. 1.7.(b) *Aedes aegypti* at rest (© L. Robertson). *A. aegypti* is easily recognized by the contrasting black and white rings on its legs and the lyre-shaped pattern of silver markings on the upper surface of the thorax.

Life cycle

The eggs are laid singly on damp surfaces just above or near the water line in temporary pools and other habitats where the water level rises and falls. They can withstand desiccation for many months and hatch only when flooded with water. All species of *Aedes* which occur in regions with cold winters survive these periods in the egg stage. Some species breed in coastal salt marshes and swamps that are flooded at intervals by unusually high tides or heavy rains, while others have adapted to agricultural irrigation practices.

Aedes aegypti mainly breeds in the domestic environment: its preferred habitats are water storage tanks and jars inside and outside houses, and roof gutters, leaf axils, bamboo stumps and temporary containers such as jars, drums, used car tyres, tin cans, bottles and plant pots. All these habitats typically contain relatively clean water.

Aedes albopictus originally occurred only in Asia and Madagascar but recently invaded North and South America, as well as West Africa, where it may become important in the transmission of dengue and other viral diseases. Like *Aedes aegypti*, it breeds in temporary containers but prefers natural ones in forests, such as tree holes, leaf axils, ground pools and coconut shells, and breeds more often outdoors in gardens and less frequently indoors in artificial containers.

Behaviour

Aedes mosquitos bite mainly in the morning or evening. Most species bite and rest outdoors but in tropical towns *Aedes aegypti* breeds, feeds and rests in and around houses.

Mansonia mosquitos

Mansonia mosquitos are mostly found in marshy areas in tropical countries. Some species are important as vectors of brugian filariasis in south India, Indonesia and Malaysia.

The body, including the legs and wings, is covered with dark-brown and pale scales, giving it a rather dusty appearance, as if sprinkled with salt and pepper.

Life cycle

The species that transmit filariasis normally lay their eggs in masses that are glued to the lower sides of plants hanging or floating near the water surface. Because the larvae and pupae attach themselves to aquatic plants for the purpose of breathing they occur only in water bodies containing permanent vegetation, such as swamps, ponds, grassy ditches and irrigation canals, and may be difficult to find. They can also occur in deeper water where there is floating vegetation, and are very often attached to the underwater parts of floating aquatic weeds (*Eichhornia, Pistia, Salvinia*) and grasses (Fig. 1.8).

Behaviour

Mansonia species usually bite at night, mostly out of doors, but some species enter houses. Resting after a blood-meal normally takes place out of doors.

Blackflies

Blackflies (Fig. 1.9) occur around the world and there are about 1300 species. Usually black in colour, they are 1.5 - 4 mm in length. The blackflies are vectors of onchocerciasis or river blindness in Africa and in Central and South America. In Africa the most important species are *Simulium neavei* and members of the *Simulium damnosum* complex. In addition, blackflies are a serious nuisance in many parts of the world because of their painful bites and the sometimes enormous numbers involved in attacks. Blackfly bites may cause localized swelling and inflammation and intense irritation of the skin lasting days or weeks. Normally blackflies do not enter houses.

Life cycle

The eggs are laid in fast-flowing, oxygen-rich water in streams, rivers and spillways of dams (Fig. 1.10). In the tropics, the eggs hatch after 1 - 4 days. The larvae do not swim, remaining attached to submerged vegetation, stones and other substrates. They feed on small suspended particles. Depending on the climate, the larval stage lasts from one week to several months. The pupae are also attached to submerged objects and the adults emerge after 2 - 6 days.

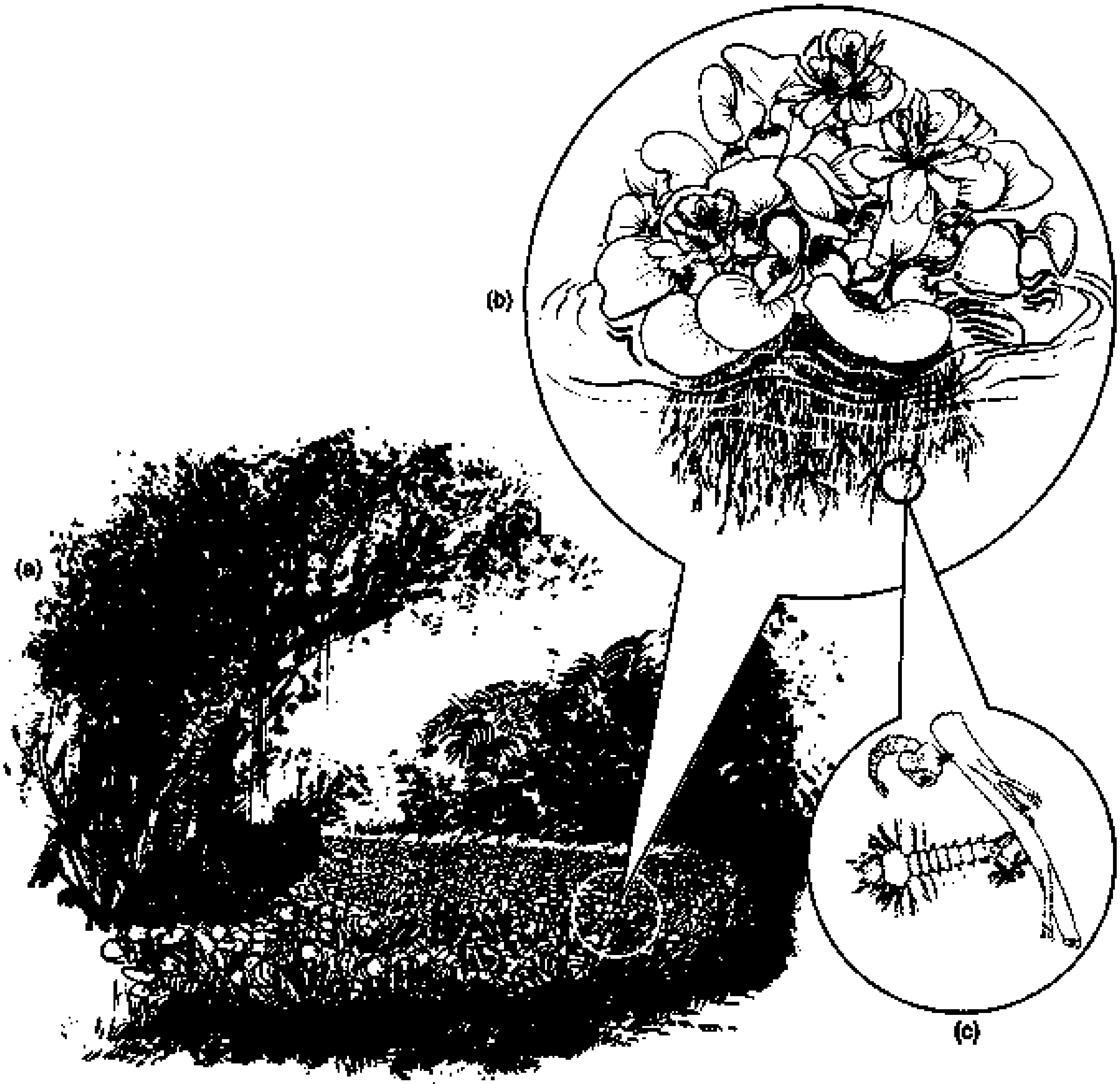

Fig. 1.8. A canal in which the water surface is covered with floating mats of water hyacinth (*Eichhornia*) (a) (© L. Robertson). On the right (b), the water hyacinth in more detail (© L. Robertson). *Mansonia* larvae and pupae are attached to the roots, from which they take oxygen for breathing (c) (*2*).

Behaviour

Blackflies bite in the daytime and outdoors, especially along riverbanks. Certain species show a strong preference for biting specific parts of the body. For example,

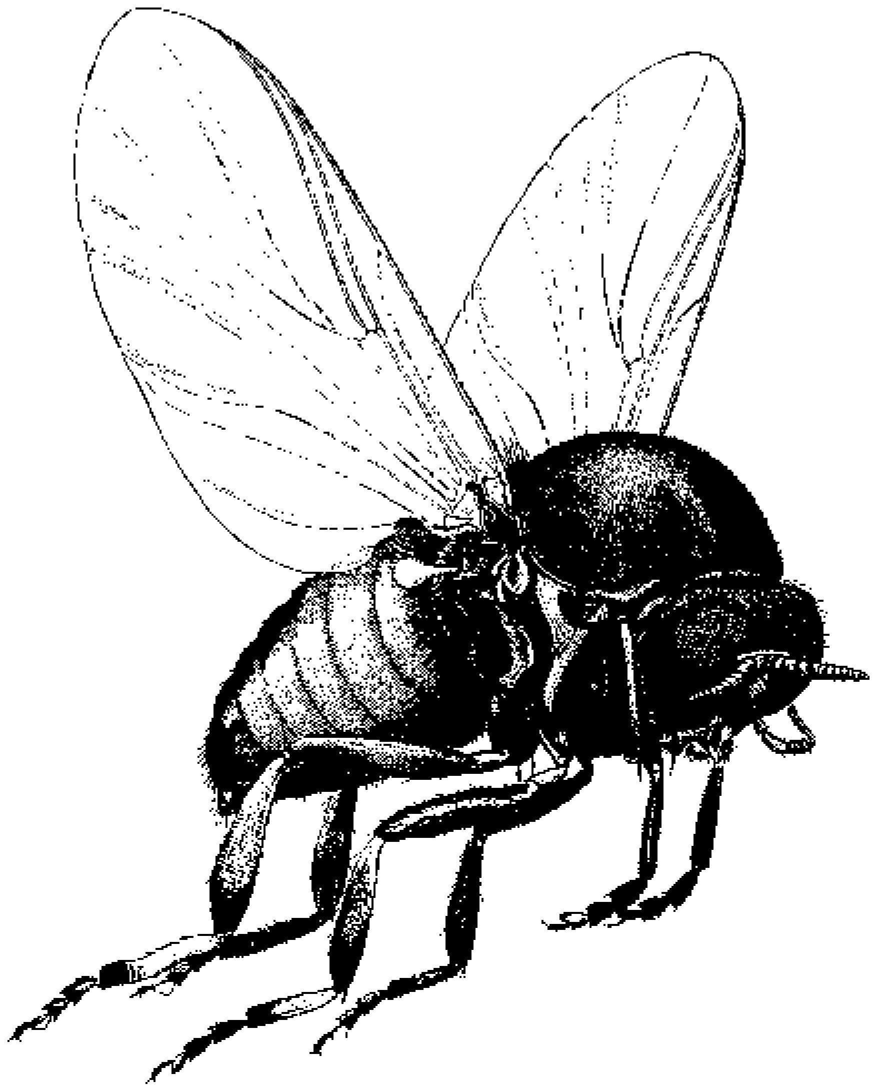

Fig. 1.9.(a) Blackfly in flight (© WHO);

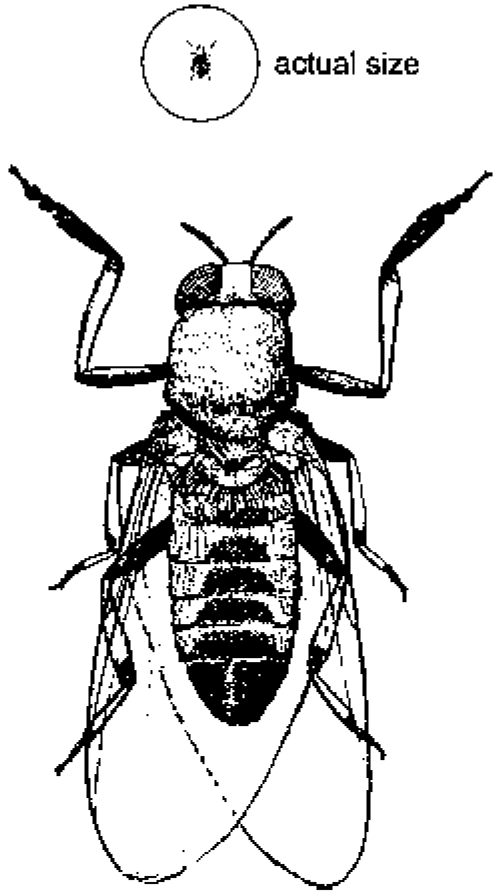

Fig. 1.9.(b) Blackfly at rest (by courtesy of the Natural History Museum, London).

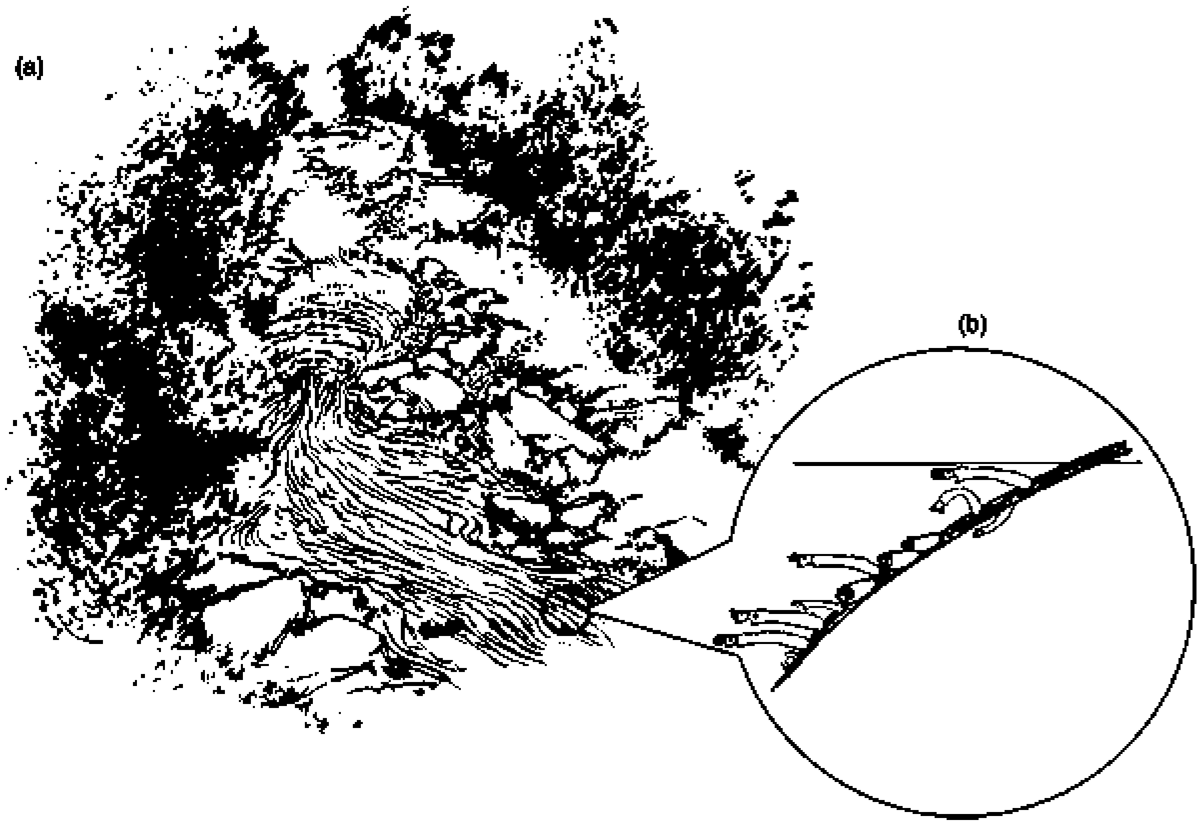

Fig. 1.10. (a) Typical *Simulium* breeding site (© L. Robertson). Adult blackflies often occur in large numbers near such places. (b) Larvae attached to a leaf-blade of submerged grass (by courtesy of the Natural History Museum, London).

Simulium damnosum in West Africa mainly attacks the legs. Most species feed predominantly on birds or mammals; several feed on humans. In the tropics, blackflies digest blood-meals over a period of 2 - 3 days in outdoor resting places on trees and other natural sites.

Sandflies

Sandflies (Fig. 1.11) are small bloodsucking flies that are important as vectors of leishmaniasis and that can cause a serious but localized biting nuisance. Species that occur in the Mediterranean region can transmit sandfly fever, a viral disease also known as Pappataci fever or three-day fever.

Life cycle

Sandflies are found in various habitats, ranging from semi-desert to rainforest. They deposit their eggs in humid places on damp soil rich in humus. The larvae feed on decaying organic matter. Examples of suitable breeding sites are small cracks and holes in the ground, the ventilation shafts of termite hills, animal burrows, cracks in mud walls and masonry, and among tree roots. Large populations of sandflies can build up in family compounds where cattle are kept at night. The cattle provide an abundant source of blood, while the stables and houses provide suitable resting places

(Fig. 1.12). The life cycle may last from 1 to 4 months, depending on species and temperature, although it usually lasts less than 45 days.

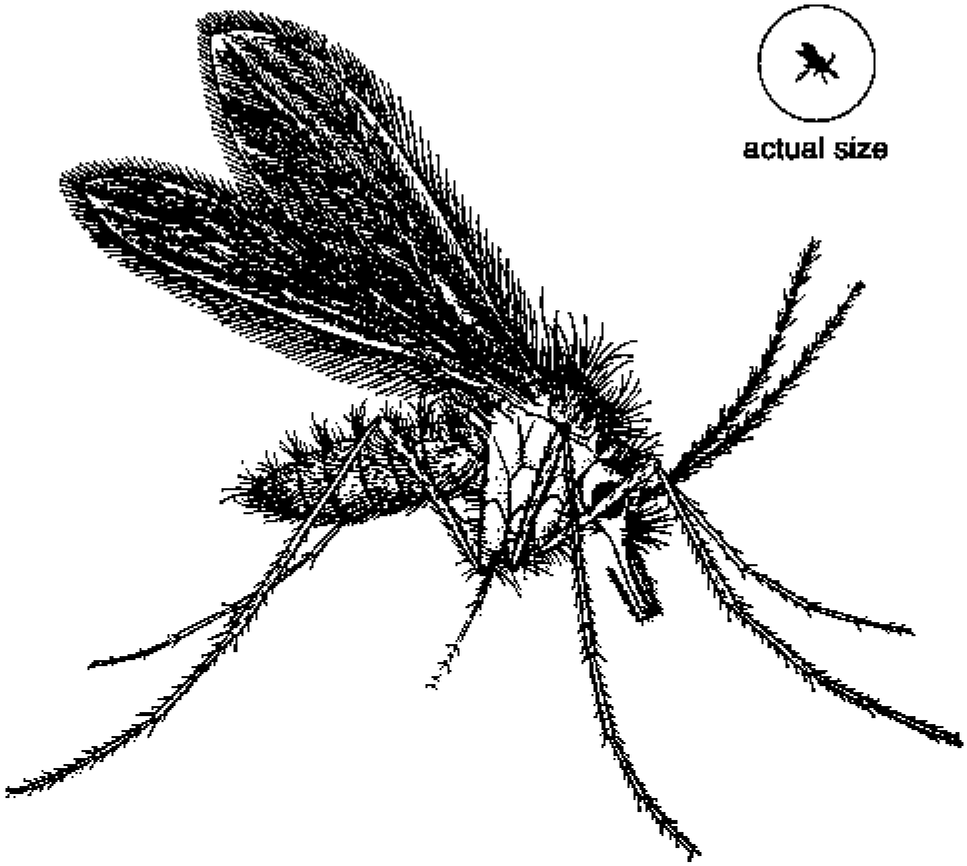

Fig. 1.11. Phlebotomine sandfly. About 1.3 - 3.5 mm in length; hairy appearance; conspicuous black eyes; long, stilt-like legs (by courtesy of the Natural History Museum, London).

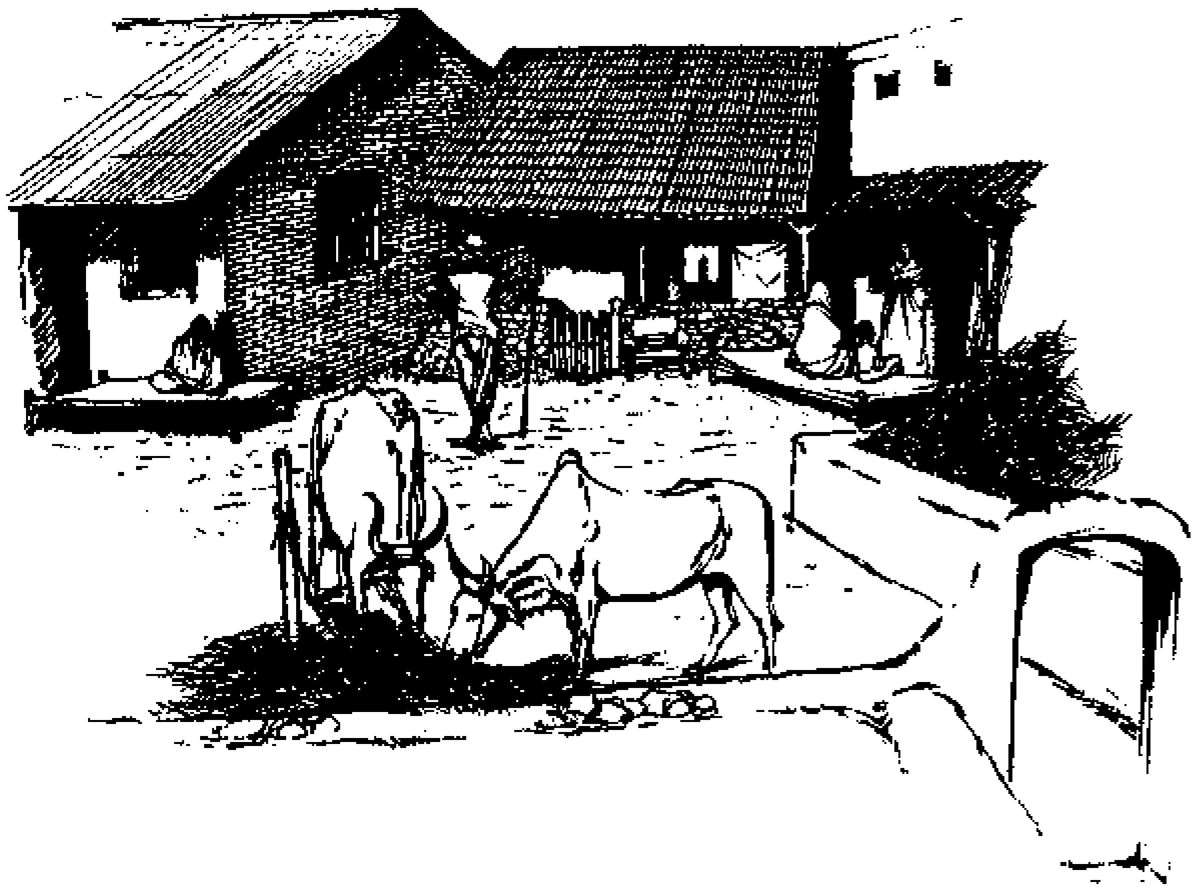

Fig. 1.12. A typical transmission site of visceral leishmaniasis.

Behaviour

The adult sandflies are weak fliers and usually stay within a few hundred metres of their breeding places. They fly in a characteristic hopping way, with many short flights and landings. As a result, biting is restricted to areas where suitable breeding sites occur. Most biting occurs outdoors but a few species also feed indoors. Most species are active at dawn and dusk and during the night, but in forests and dark rooms they may also attack in the daytime, especially if disturbed by human activities. They usually rest in the daytime in sheltered, dark and humid sites, such as those used for breeding, but also in tree holes, caves, houses and stables; other resting places near houses are crevices in walls, stacks of firewood, bricks and rubbish.

Sandflies feed on plant juices but for the most part the females need a blood- meal in order to develop eggs. Autogeny occurs in a few species. Blood is taken from humans and animals such as dogs, farm livestock, wild rodents, snakes, lizards and birds. Each sandfly species has specific preferences for its source of blood, but the availability of hosts is an important factor. The saliva of sandflies can enhance the virulence of inoculated *Leishmania* parasites. Sandfly species are only important as vectors of leishmaniasis if they feed regularly on humans.

Biting midges

Biting midges (Fig. 1.13) are bloodsucking flies, about 1.5 mm in length. The most important genus, *Culicoides*, is distributed worldwide and can cause a serious biting problem, as can the genus *Leptoconops* in the Americas. In parts of South America and Africa these insects are vectors of the human filariae parasites *Mansonella ozzardi* and *M. perstans*, which are generally considered to be harmless to humans.

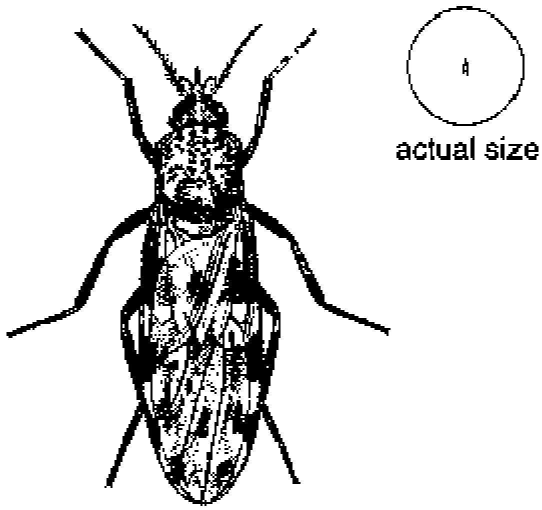

Fig. 1.13. Biting midge (by courtesy of the Natural History Museum, London).

These insects are called sandflies in some parts of the world, but they can be distinguished from the phlebotomine sandflies by the fact that the wings are folded flat over the body when the midges are at rest; furthermore, they often fly in swarms around the head or other exposed parts of the body and they do not fly in a hopping way with many short flights and landings, as do the phlebotomine sandflies.

Life cycle

Several species breed in swampy and marshy areas, including saltwater marshes and mangrove swamps, where they lay their eggs on the elevated surface of mud or wet soil. Some important pest species breed on sandy beaches near the sea. Other species lay their eggs on decaying leaf litter, humus, manure and semi-rotting vegetation, in tree holes and the cut stumps of banana plants, and on plants or objects near, or partially in, water. The larvae feed on decaying organic matter. The time taken for development from egg to adult may be 2 - 4 weeks in warm climates but up to several months in temperate regions.

Behaviour

Midges obtain blood from mammals, birds, reptiles and humans. They bite during the day and night but, for most species, biting activity peaks in the early evening. All exposed body parts are attacked. Individual midges can cause a painful bite, but they are considered to be an especially severe pest because of their habit of attacking in swarms of hundreds or thousands. Most species only bite outdoors, but indoor biting may also occur.

Some of the most important pest species breed in salt marshes and other places along coasts. In such areas they can hamper the development of tourism.

Biting midges frequently enter the tents of campers in marshy areas. People sitting on verandas and those living in open-walled houses are also frequently bitten.

Horseflies and deerflies (tabanids)

The tabanid flies (Fig. 1.14) are medium-sized to large and occur around the world. They can cause very painful bites, sometimes making outdoor activities difficult in forested and swampy areas. They are of minor importance as vectors of diseases, such as tularaemia and certain arboviral diseases. In West and Central Africa some species of the genus *Chrysops* transmit the filarial parasite *Loa loa*. The most important groups are the genera *Tabanus* (horseflies, greenheads), *Chrysops* (deerflies, mangrove flies) and *Haematopora* (clegs or stouts).

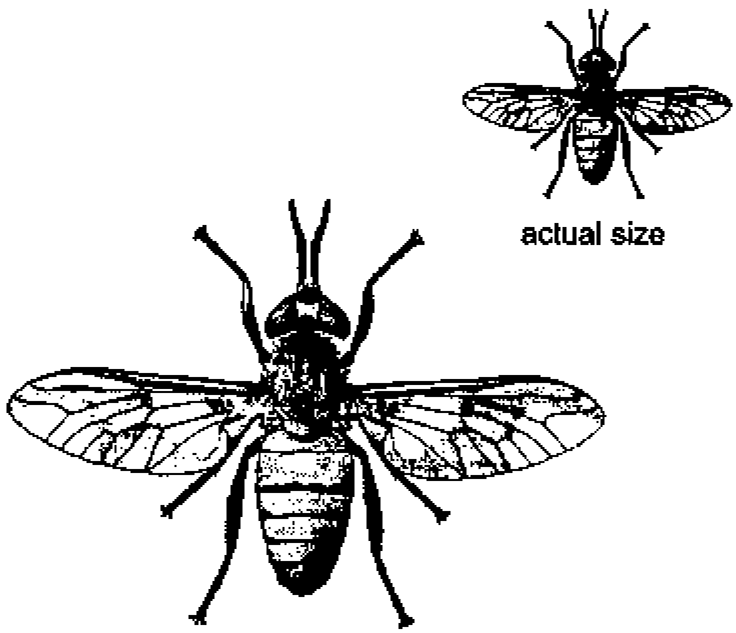

Fig. 1.14.(a) *Chrysops* spp. - *C. fixissimus* (by courtesy of the Natural History Museum, London);

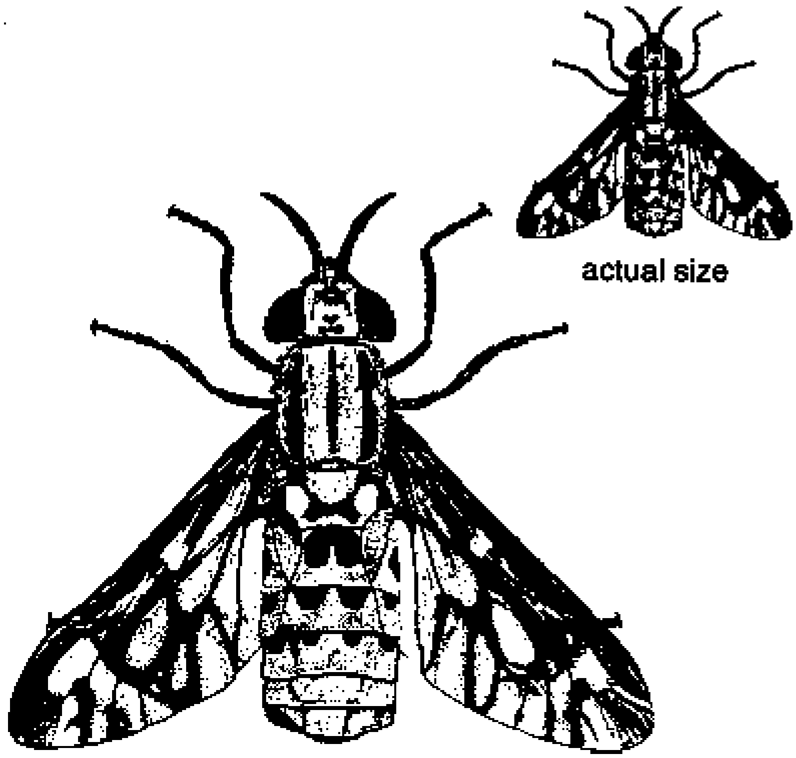

Fig. 1.14. (b) *Chrysops* spp. - *C. discalis* Williston (*1*).

The tabanids measure 5 - 25 mm in length. They are robust and strong fliers. They have a large head with conspicuous eyes which show iridescent colours. The mouthparts are large and point downward. The wings are completely clear or have a brownish colour or speckles. At rest the wings are folded flat along the body.

Life cycle

The female tabanids feed on large domestic and wild animals, such as horses, cattle and deer, and also on small mammals, reptiles and birds. In addition they feed on humans. The eggs are deposited on the underside of objects such as leaves, plant stems and small branches hanging above water. After emerging the larvae drop down on to the underlying mud or water. The larvae of most species live in mud, rotting vegetation, humus, damp soil and shallow, muddy water at the edges of pools, swamps and streams. They generally feed on decaying material of animal or vegetable origin. Depending on the species the larvae are between 1 and 6 cm long. Development from egg to adult may take 1 - 3 years.

Behaviour

Most species feed in the daytime, especially during the sunniest hours. They hunt by sight and can fly over long distances. They are most common in forests and swampy areas with woody vegetation. They do not usually enter houses to feed. Their bites are deep and painful and the wounds often continue to bleed after the flies have left. They need a large quantity of blood and are frequently disturbed while feeding; for this reason they take several small blood-meals from the same or different sources.

Stable flies

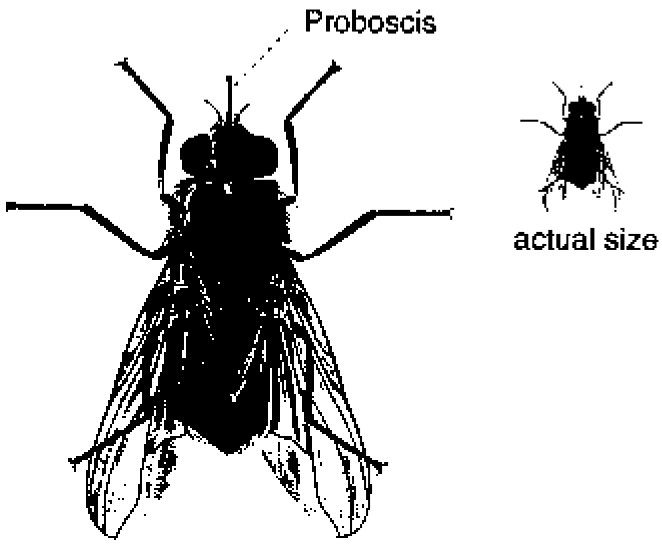

Fig. 1.15. A stable fly (by courtesy of the Natural History Museum, London).

Stable flies (*Stomoxys*) occur around the world. They look similar to houseflies and are also known as biting houseflies. They can be distinguished from similar-looking non-biting flies by their forward-pointing mouthparts (Fig. 1.15). They cause painful bites and are a serious nuisance to humans and animals. They are not important as vectors of disease. However, in South America they sometimes play a role in the transmission of myiasis by carrying the eggs of the myiasis-producing fly *Dermatobia hominis*. In Africa they can be confused with tsetse flies, which also have forward-directed mouthparts. However, they are smaller than tsetse flies and the wings of stable flies do not overlap at the back when at rest.

Life cycle

Both male and female stable flies feed on animals, including horses, cattle and dogs, and on humans. The eggs are laid in wet and decaying organic material, such as horse manure, compost and piles of rotting plant debris. The larvae are creamy white in colour and resemble those of the housefly. The pupae develop in dry areas in the soil. Development from egg to adult takes from 12 days to 2 months, depending on the temperature.

Behaviour

Stable flies bite in the daytime and mostly out of doors, although indoor biting may also occur. The insects are most common near farms and places where horses are kept. In the absence of animals they may increase their attacks on humans. They mostly feed on the legs.

Public health importance

Nuisance

Some species of biting Diptera attack in large numbers and may cause considerable annoyance. In some areas, particularly in the northern areas of temperate regions, outdoor activities can be made impossible by swarms of biting mosquitos. Certain species, especially the larger biting Diptera such as the tabanids and stable flies, and also blackflies and some *Aedes* mosquitos, cause painful bites sometimes followed by localized swelling and inflammation. Irritation may last for weeks.

People are likely to be motivated to use personal protection and other control methods when biting densities are high. Where the biting Diptera are involved in disease transmission, increased self-protection against biting may automatically result in a reduced risk of contracting infection. However, some diseases can be transmitted while biting densities are low and people may even be unaware that they have been bitten. This is particularly true for malaria transmission in some rainforest areas. In the absence of the nuisance factor it may be difficult to motivate people to protect themselves against infection.

Malaria

Malaria is caused by single-celled protozoan parasites of the genus *Plasmodium*. The parasites are transmitted from person to person by anopheline mosquitos.

Four species of malaria parasite infect humans:

- *Plasmodium falciparum* occurs throughout tropical Africa and in parts of Asia, the Western Pacific, South and Central America, Haiti and the Dominican Republic;

- *Plasmodium vivax* is almost absent from Africa but is the predominant malaria parasite in Asia and South and Central America;

- *Plasmodium malariae* is found worldwide but has a very patchy distribution;

- *Plasmodium ovale* occurs mainly in tropical West Africa and rarely in the Western Pacific.

Malaria is widespread in the tropics and also occurs in subtropical and temperate regions (Fig. 1.16). In 1993, it was estimated that about 2020 million people in some 90 countries or territories are at risk of infection, and that some 300 - 500 million people are ill with malaria each year, 1.5 - 2.7 million of whom die. Malaria is among the most important causes of death and illness in Africa, especially among children and pregnant women. Travellers, tourists and immigrants may be at high risk.

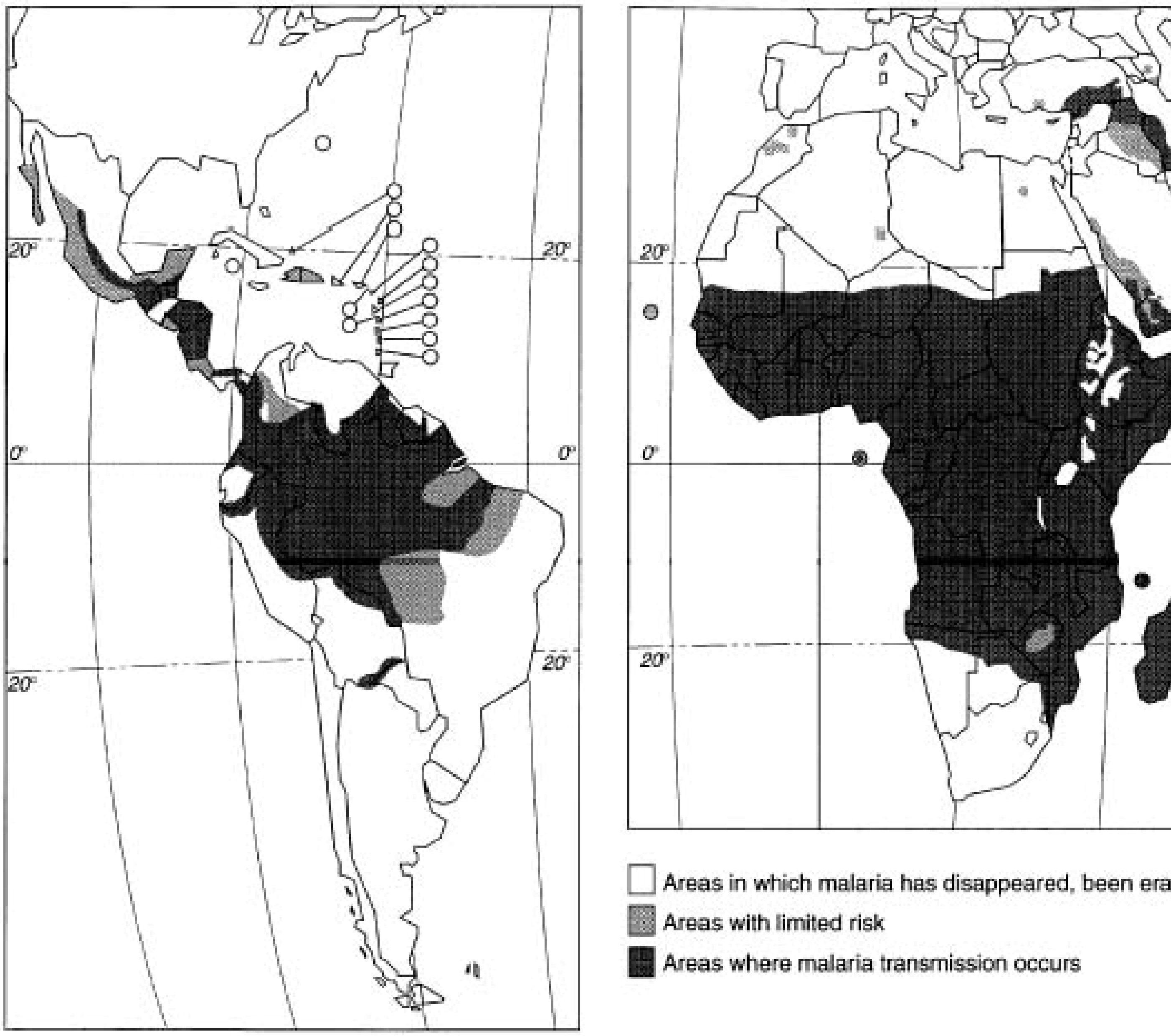

Fig. 1.16. Approximate distribution of malarious regions, 1996 (© WHO).

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Treatment is complicated by the spread of strains of *Plasmodium falciparum* resistant to the commonly used antimalarial drugs and the high cost and toxicity of alternative drugs. In addition, mosquito control by indoor house spraying is increasingly difficult because of the development of insecticide resistance in many species of *Anopheles*. Many malaria control programmes are hampered by financial and operational problems.

Transmission

Malaria parasites enter the human body via the bite of a malaria-carrying mosquito of the genus *Anopheles*. The parasites invade the liver via the bloodstream and multiply. During this period, the victim does not feel ill. After about nine days or longer, depending on the species, the parasites (called merozoites) enter the bloodstream, invade the red blood cells, and again multiply. A few days after the appearance of the first symptoms some merozoites develop into gametocytes, the sexual stage in the life cycle.

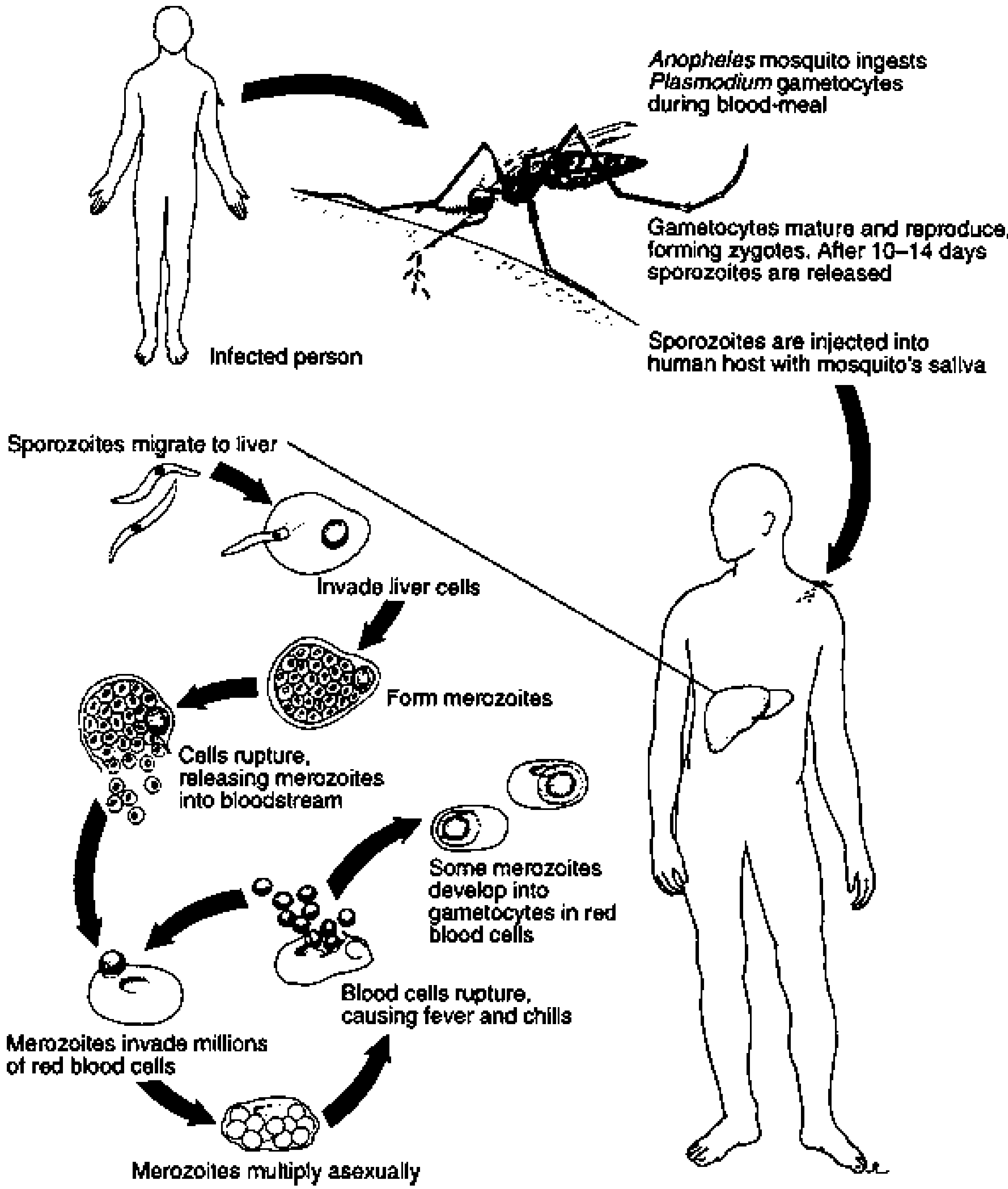


Fig. 1.17. Life cycle of the malaria parasite (by Taina Litwak for the United States Agency for International Development's VBC Project).

Anopheles mosquitos that feed on a person with gametocytes in the blood become infected and the parasites undergo another phase of reproduction in the insects. At the end of this process a new generation of malaria parasites, called sporozoites, migrates to the salivary glands of the mosquito where they remain until the insect bites a person and injects the sporozoites together with its saliva into a new human host. The sporozoites then invade the liver and the cycle is repeated (Fig. 1.17). The cycle in the mosquito usually lasts between 9 and 12 days.

Malaria can also be transmitted accidentally by the transfusion of blood containing malaria parasites, or through contaminated needles or syringes. During pregnancy, fetuses can become infected with parasites from the blood of the mother (transplacental transmission).

Clinical symptoms

Malaria begins as an influenza-like illness with attacks of fever eight days or more after the bite of an infected mosquito. Cycles of fever, shaking chills, drenching sweats and headaches may develop. The frequency and severity of the fever depends on the malaria species involved but it usually lasts 2 - 3 days. The attacks of fever coincide with waves of parasite multiplication and the destruction of red blood cells. Long-lasting infections often result in enlargement of the liver and spleen.

Malaria caused by *P. falciparum* does not always show this cyclic pattern. It is the most severe type of malaria and, if untreated, may progress to shock, kidney and liver failure, coma or death. Death is often due to parasitized red blood cells blocking the narrow blood vessels in an organ of the body. If blood vessels of the brain are affected, the condition is called cerebral malaria. Prompt treatment is essential to prevent damage to the brain or any other organ. *P. vivax, P. malariae* and *P. ovale* are generally not life-threatening but death may occur in very young children and old and sick people.

With *P. vivax* and *P. ovale* malaria the interval between attacks of fever is typically two days and for *P. malariae* it is three days*. For P. falciparum* malaria the intervals are irregular, usually about 36 - 40 hours but shorter intervals are also common. The duration of an untreated first attack may last from a week to a month or longer.

Attacks of illness after an interval of weeks or more, called relapses, do not occur with *P. falciparum* but are common in *P. vivax* and *P. ovale* infections. Relapses may occur at irregular intervals for up to two years with *P. vivax* and for up to five years with *P. ovale*. Infections with *P. malariae* may persist for up to 50 years with periods of fever returning at intervals.

Immunity

Where malaria has long been highly endemic, as in many parts of Africa, people are infected so frequently that they develop a degree of immunity. In many cases they may carry malaria parasites without showing any symptoms. Epidemics of malaria which cause serious illness are often related to the movement of nonimmune groups of people into highly endemic areas (for example, people in search of work, refugees and soldiers).

Prevention and treatment

Malaria can be prevented if measures are taken to avoid being bitten by anopheline mosquitos. Protective measures include the wearing of protective clothing, the use of repellents on exposed skin, mosquito coils and other insecticide vaporizers, sleeping under mosquito nets, and improving dwellings.

Because it is not possible always to be sure about the effectiveness of such measures, visitors to malarious areas should use prophylactic drugs to prevent the development of the disease in the event of receiving an infective bite. Information on the most appropriate malaria prophylaxis should be obtained from the health authorities familiar with the local situation.

Persons showing signs of malaria should be treated promptly. If possible a blood sample should first be examined microscopically in a laboratory (Fig. 1.18). Prompt treatment of non-immune patients and of children is important because an infection can become life-threatening within hours.

The drugs used for the treatment of infections should be effective against the locally occurring strains of the malaria parasites.

Malaria control

In areas with intense transmission of malaria, control activities aim to stop preventable deaths and minimize suffering from the disease. Essential to this strategy are basic health services that provide prompt diagnosis and adequate treatment. An efficient system needs to be in place for referring patients with severe malaria and those who have not responded to standard treatment regimens. Vector control measures may be included in certain areas as part of a properly designed control programme.

Where the health infrastructure is sufficiently well developed, services should aim to prevent mortality and illness among vulnerable groups with low immunity, such as infants, pregnant women and groups of workers. Such groups can be given additional protection through the use of mosquito control measures. Chemoprophylaxis is recommended for travellers, children under five and pregnant women in areas of high endemicity.

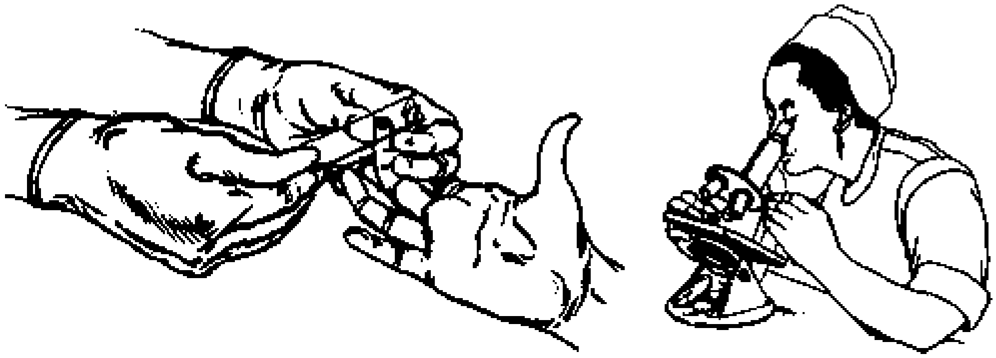


Fig. 1.18. Malaria may be confirmed by taking a sample of blood and examining it under a microscope.

In areas with low or moderate transmission of malaria, in those with advanced health services with well trained and experienced personnel, and in priority areas such as those with development projects, attempts may be made to reduce the prevalence of malaria by community-wide mosquito control measures.

In areas subject to epidemic risk, quick-acting and timely vector control measures, such as insecticide spraying, play an important role in the control or prevention of epidemics.

Apart from the input of health services in the planning and management of activities, it is also important for communities to participate in control efforts. Sufficient resources have to be ensured for the long-term maintenance of improvements obtained. In developed countries with advanced professional capabilities and sufficient resources, it is possible to aim at a countrywide eradication of malaria. Eradication has been achieved in southern Europe, most Caribbean islands, the Maldives, large parts of the former USSR and the USA.

As most anopheline mosquitos enter houses to bite and rest, malaria control programmes have focused primarily on the indoor application of residual insecticides to the walls and ceilings of houses. House spraying is still important in some tropical countries but in others its significance is diminishing because of a number of problems (see Chapter 9), which, in certain areas, have led to the interruption or termination of malaria control programmes. There has been increased interest in other control methods that would avoid some of the problems related to house spraying. Methods that are less costly and easier to organize, such as community-wide use of impregnated bednets, and methods that bring about long-lasting or permanent improvements by eliminating breeding places are now being increasingly considered.

Lymphatic filariasis

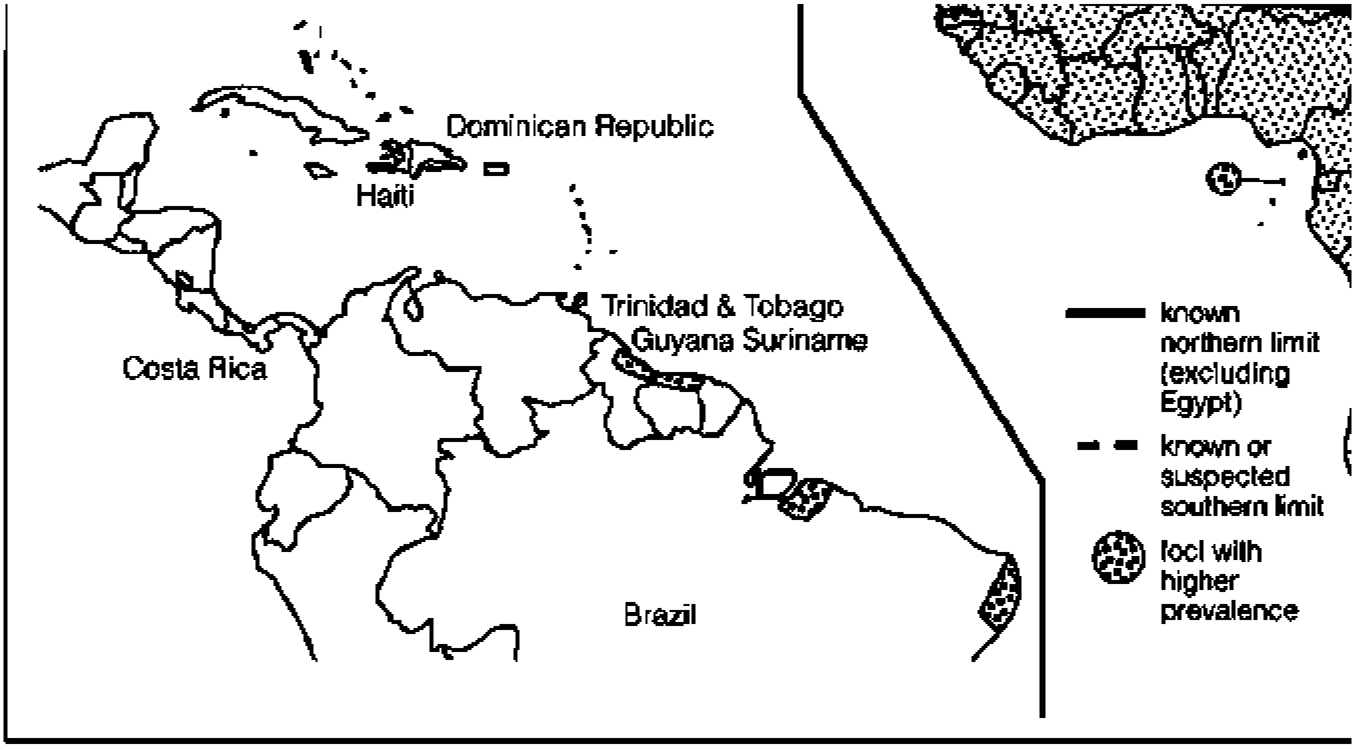
Lymphatic filariasis is caused by three species of parasitic worm which occur in the lymph vessels and may cause huge swellings of the limbs and other parts of the body. Although the disease causes much suffering and disability it is rarely life-threatening.

• Bancroftian filariasis, caused by *Wuchereria bancrofti*, is mainly transmitted by *Culex quinquefasciatus* and by some *Anopheles* and *Aedes* species. In 1996, it was estimated that some 107 million people were infected in parts of China, India, other parts of south-east Asia, the Pacific Islands, tropical Africa, and South and Central America (Fig. 1.19).

• Brugian filariasis, caused by *Brugia malayi* and *B. timori*, was estimated to infect some 13 million people in 1996, mainly in south-east Asia. Its main vectors are the *Mansonia* species. *B. timori* occurs on the islands of Flores, Timor and Alor, to the east of Java, and is transmitted by *Anopheles barbirostris* (Fig. 1.19).

Transmission

The adult worms live in the lymphatic vessels in the human body and produce embryos called microfilariae, which circulate in the bloodstream and are picked up by biting mosquitos. After developing for several days in the mosquito, infective larvae enter the skin when the mosquito feeds, migrate to the lymph nodes and develop into adult worms in the lymph vessels (Fig. 1.20). The chance of an infection being established from a single bite by an infected mosquito is very low. The adult worms can live for many years, giving rise to large numbers of microfilariae in the blood.


Dominican Republic
Haiti
Trinidad & Tobago
Guyana Suriname
Costa Rica
Brazil
known northern limit (excluding Egypt)
known or suspected southern limit
foci with higher prevalence

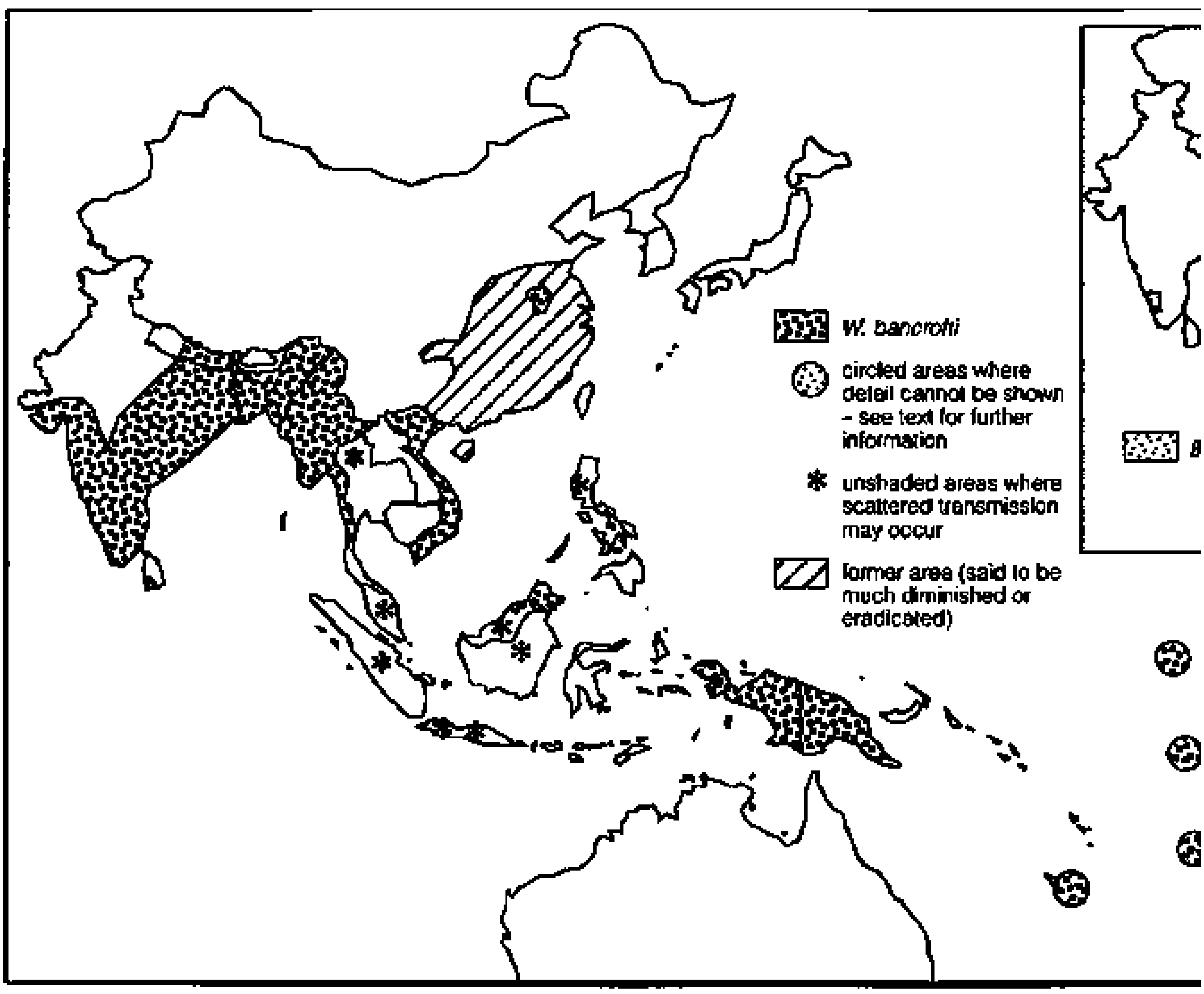

W. bancrofti
circled areas where detail cannot be shown – see text for further information
unshaded areas where scattered transmission may occur
former area (said to be much diminished or eradicated)

Fig. 1.19. Geographical distribution of lymphatic filariasis, 1992 (© WHO).

WHO 92353/WHO 92354

Bancroftian filariasis occurs in two forms: in the most common form the microfilariae circulate in the blood at night, whereas in the second form they occur continuously in the blood but increase in number during the day. The vectors of the first form are *Culex quinquefasciatus* and certain *Anopheles* species (which bite at night). The second form is found in the South Pacific and in some rural areas in south-east Asia where the main vectors are daytime-biting mosquitos such as certain *Aedes* species.

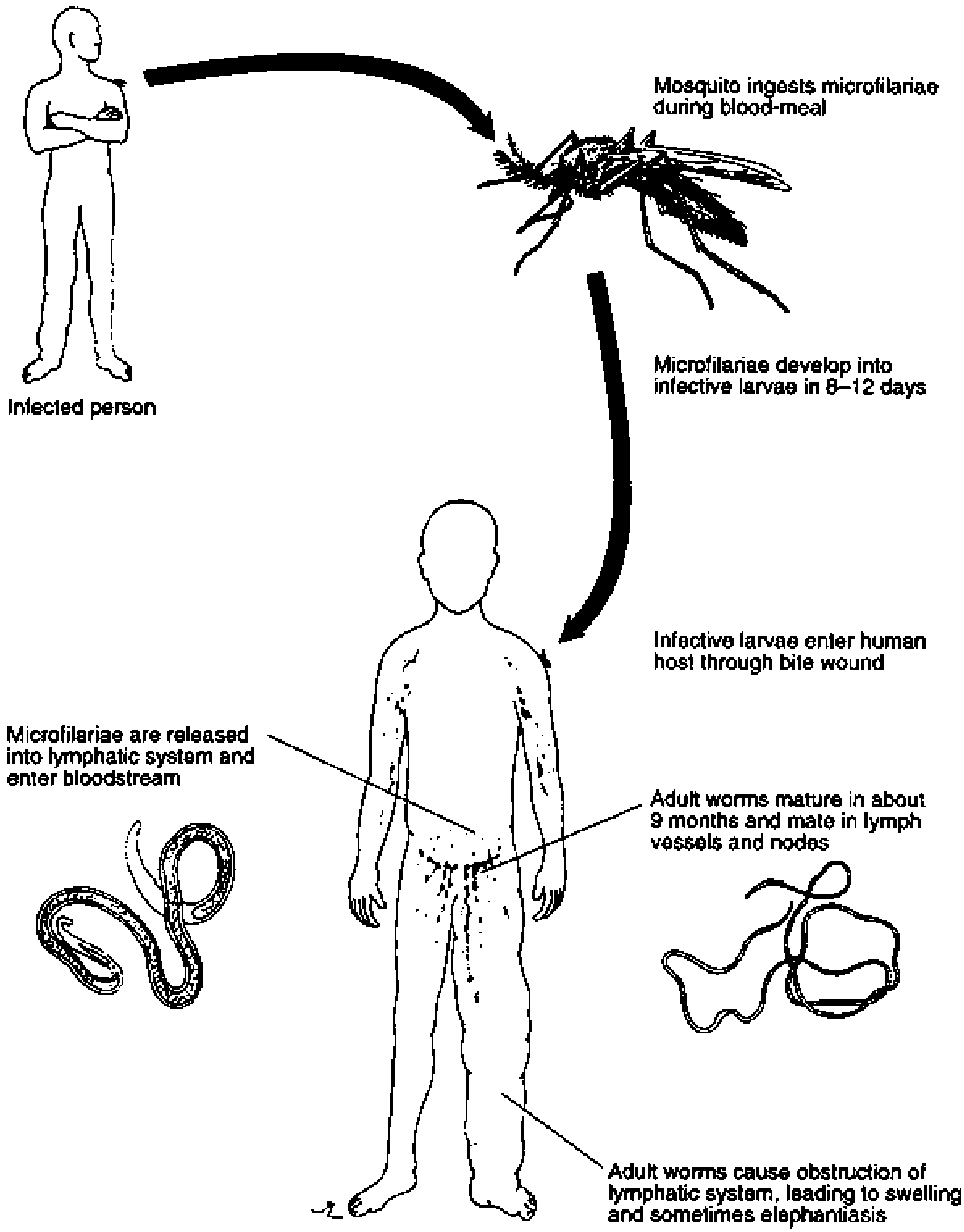


Fig. 1.20. Life cycle of filarial parasites (by Taina Litwak for the United States Agency for International Development's VBC Project).

In rural areas, bancroftian filariasis is mainly transmitted by some *Anopheles* species that are also malaria vectors, and by *Aedes*. Urban bancroftian filariasis typically occurs in slums in developing countries. It is transmitted by *Culex quinquefasciatus*, which breeds in polluted water in drains, cesspits and ditches.

Brugian filariasis, caused by *B. malayi*, also occurs in two forms, of which the most common is transmitted at night and the other during both day and night. The first form occurs in rural populations in rice-growing areas in Asia. It is transmitted by night-biting *Anopheles* species and by *Mansonia* species which breed in swamps and ponds with aquatic vegetation. The second form is mainly a parasite of monkeys living in swamps. *Mansonia* species breeding in swampy forests in Indonesia and Malaysia may infect people living nearby.

Fig. 1.21. Elephantiasis (permanent swelling) of the leg due to lymphatic filariasis.

Brugian filariasis caused by *Brugia timori* is transmitted only by *Anopheles barbirostris.*

Clinical symptoms

The clinical symptoms and signs are mainly determined by the duration of the infection. The adult worms, which live in the lymphatic vessels, can cause severe inflammation of the lymphatic system and acute recurrent fever. Secondary bacterial infections are a major factor in the progression towards lymphoedema and elephantiasis, the characteristic swelling of the limbs, genitalia and breasts (Fig. 1.21).

Prevention and treatment

The transmission of filariasis is much less efficient than that of malaria, and prophylactic treatment for travellers is not, therefore, recommended. The risk of infection can be reduced by taking measures to prevent mosquito bites or reduce mosquito numbers.

Suspected cases can often be confirmed by detection of microfilariae in samples of blood examined microscopically. A new diagnostic method uses an immunological procedure to detect circulating filarial antigen in the blood. The test is as sensitive and specific as examination of blood by microscopy, and offers the advantage that samples can be collected during the day, even when the microfi-lariae are nocturnally periodic. People who are infected can be treated with diethylcarbamazine (DEC). This has been used in some areas for the mass treatment of infected people to reduce morbidity and transmission. DEC is much more lethal to the microfilariae than to the adult worms, which may only be killed after prolonged treatment. The death of microfilariae due to the action of DEC may cause nausea and other unpleasant, but not dangerous, side-effects, which sometimes discourage people from completing courses of treatment.

Control

Filariasis should be easier to control than malaria because of the inefficiency of transmission from mosquitos to humans and because of the long period before symptoms of infection become serious, during which time drug treatment can be effective. However, in practice, control is difficult because it takes a long time to eliminate the worm reservoir in the human host and because of a lack of compliance by communities.

The new approach to control of filariasis is based on annual treatment of populations in endemic areas with a single dose of DEC and ivermectin, given alone or (preferably) in combination (*3*). The combination of these two drugs also reduces or eliminates other parasitic worm infections and scabies. However, ivermectin alone is preferred in areas endemic for onchocerciasis or loiasis. Treatment should preferably be continued for at least five years.

Vector control measures, when practicable, are carried out in addition to drug treatment. The control of *Culex* is normally based on measures aimed at the prevention of breeding. The control or elimination of breeding sites in polluted water is possible by improving sanitation systems and hygiene in general. Where such improvements are impossible or economically unfeasible, larvicides or polystyrene beads can be applied to breeding sites. Because of the pollution of breeding sites, not all larvicides are effective and relatively high dosages are needed.

Indoor residual spraying is generally not very effective against *Culex quinquefasciatus*, at least partly because of this species' habit of resting on unsprayed objects, such as clothes, curtains and other hanging fabrics, rather than on walls and ceilings. A practical problem in urban areas is the large number of rooms that would have to be sprayed.

The most commonly used method of controlling the *Mansonia* vectors of brugian filariasis is to remove or destroy the aquatic vegetation to which the larval and pupal stages are attached. Sometimes, as for instance in swamp forests in parts of Indonesia and Malaysia, larval control measures are impracticable because of the large extent of the breeding areas. In such situations the main emphasis should be on the prevention of mosquito bites by means of self-protection.

Mosquito-borne viral diseases

The viruses that are transmitted by mosquitos and other arthropods are called arboviruses (arthropod-borne viruses). Approximately 400 different arboviruses are known; they usually occur in animals and are sometimes transmitted from animals to humans by mosquitos. The most important arbovirus infections transmitted by mosquitos are yellow fever, dengue and several forms of encephalitis. The vectors are *Aedes, Culex* or, in a few cases, *Anopheles* species.

Yellow fever

Yellow fever is an acute disease of short duration which often causes death. The disease starts with a high fever, headache, body aches, vomiting and sometimes jaundice (which gives the patient a yellow colour). This is followed by internal haemorrhages (bleeding) and vomiting. Death may occur within three days after the onset of the disease.

Transmission and distribution

The yellow fever virus mainly occurs in populations of monkeys in dense forests and gallery forests in Africa and South and Central America (Fig. 1.22). It is transmitted from monkey to monkey by forest-dwelling mosquitos (*Aedes* species in Africa, *Haemagogus* and *Sabethes* in South and Central America; Figs. 1.23 and 1.24). These mosquitos occasionally bite humans when they enter forests and may thus transmit the virus from the monkey reservoir to the human population. There is evidence in some areas of endemicity that the virus is maintained in mosquito populations through transovarial transmission in the absence of a vertebrate reservoir.

In Africa, monkeys sometimes leave the forest in search of bananas in plantations and may then infect the local mosquito species, which in turn infect humans living or working on the plantations. People infected in or near forests can carry the virus to rural or urban areas where *Aedes aegypti* or related mosquitos can pick it up and transmit it among the human population. Such situations can result in serious epidemics and many deaths.

In the Americas, urban outbreaks used to be extremely severe but have not occurred since 1954. However, the risk remains and cases are reported each year among people working in forests. In Africa, urban or rural outbreaks are occasionally reported from areas near forests and may cause thousands of deaths. People working in forests also become infected regularly. Yellow fever has never been reported in Asia.

Prevention and control

Yellow fever is best prevented by immunization, which is recommended for all persons working in or visiting forests where yellow fever occurs. Immunization is also indicated for people in urban or rural areas at risk.

Vaccination normally provides protection for at least 10 years and revaccination every 10 years is required by the port or frontier health authorities in a number of tropical countries (*4*).

Epidemics can be controlled by vaccinating all persons living in affected areas; by space-spraying with insecticides against adult mosquitos; and by appropriate larval control measures. Non-immunized people can reduce the risk of infection by protecting themselves from mosquito bites with protective clothing, repellents and screens to prevent daytime biting.

Fig. 1.22.(a) Areas of Africa where yellow fever is endemic, 1995 (© WHO).

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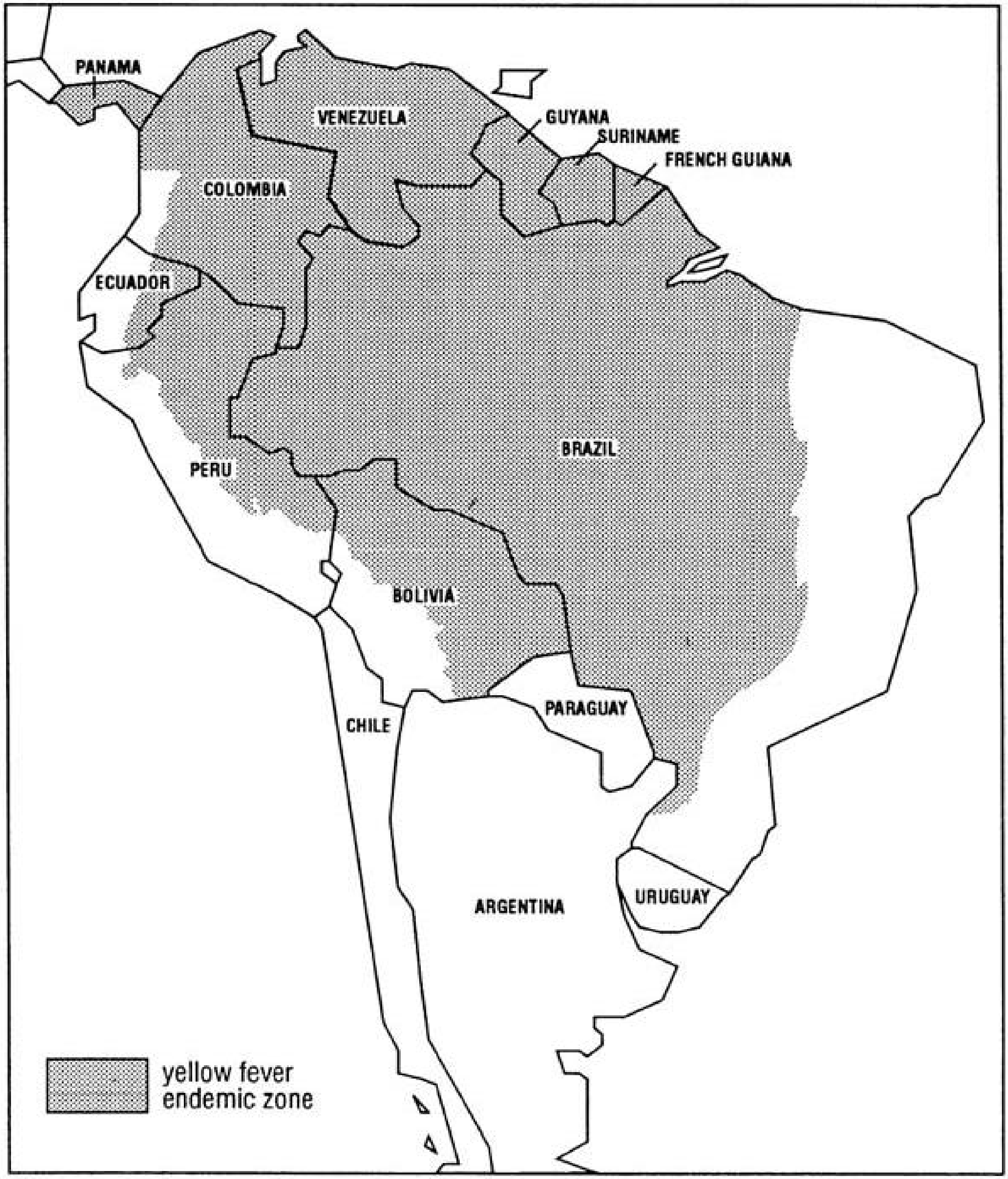

Fig. 1.22.(b) Areas of Central and South America where yellow fever is endemic, 1995 (© WHO).

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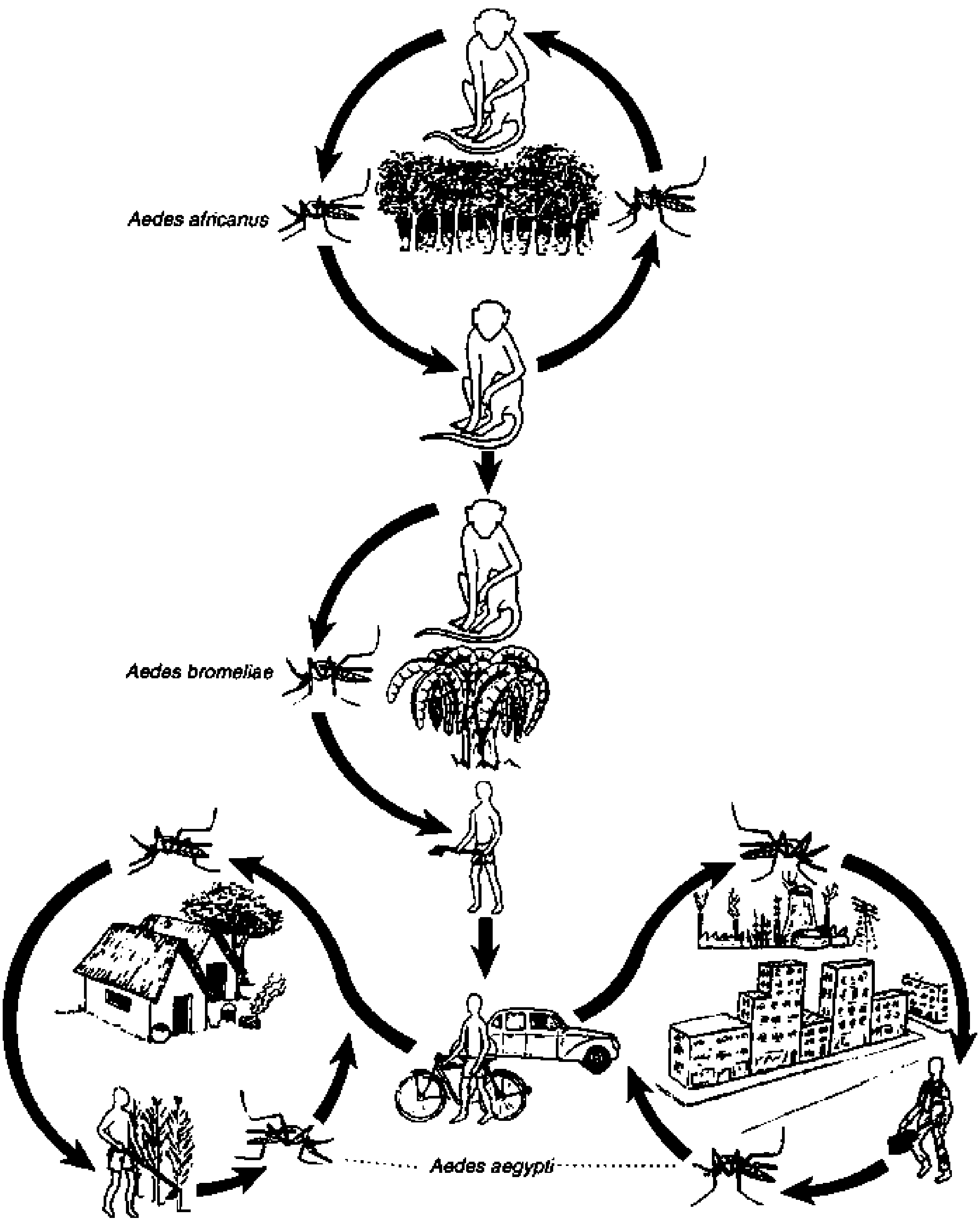


Fig. 1.23. Sylvatic, rural and urban transmission cycles of yellow fever in Africa (*2*).

Dengue and dengue haemorrhagic fever

Dengue is caused by several closely related viruses, called dengue types 1, 2, 3 and 4. The disease is transmitted from person to person mainly by *Aedes aegypti*, but *Aedes albopictus* can also act as a vector.

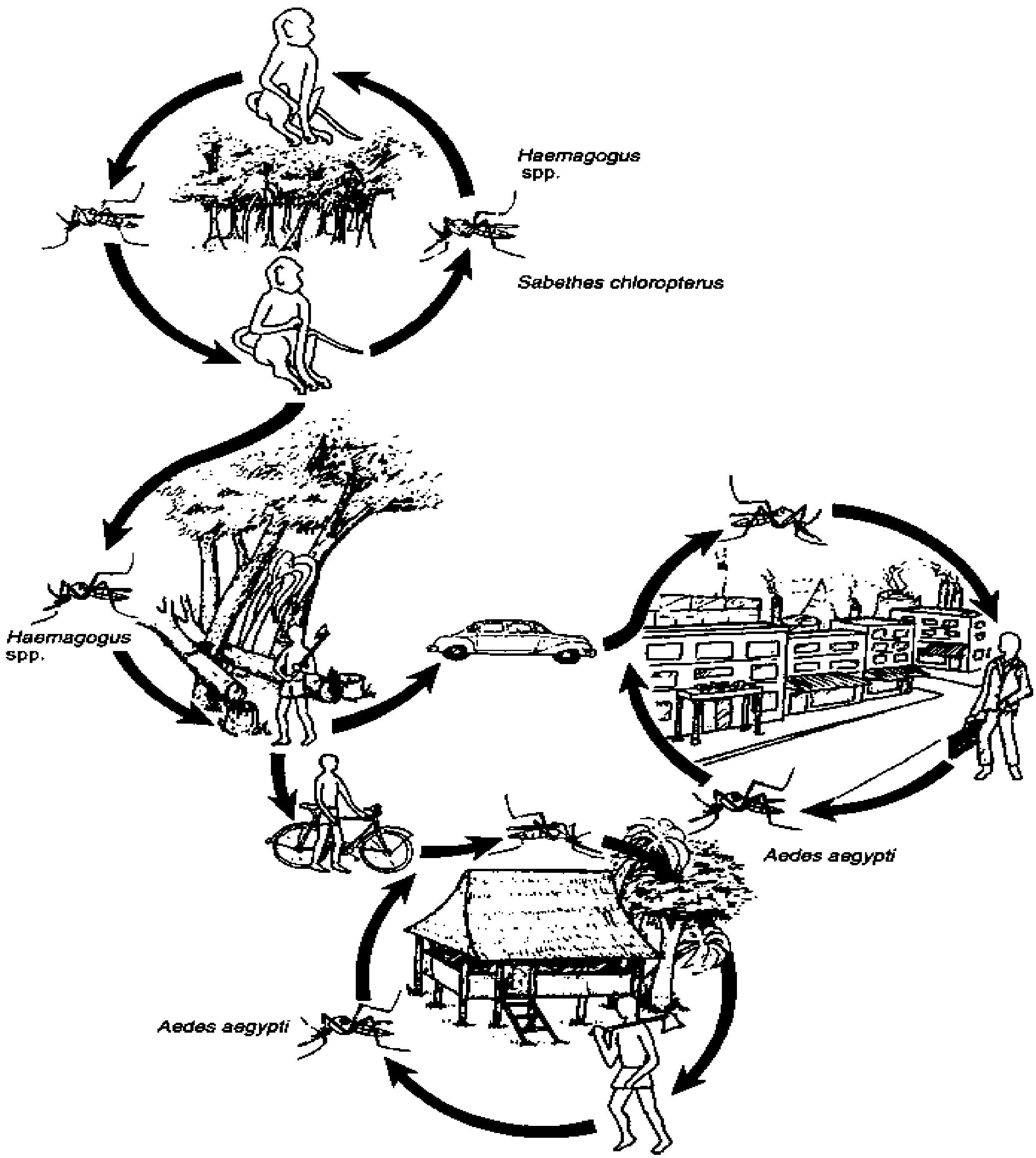


Fig. 1.24. Jungle, rural and urban transmission cycles of yellow fever in Central and South America (*2*).

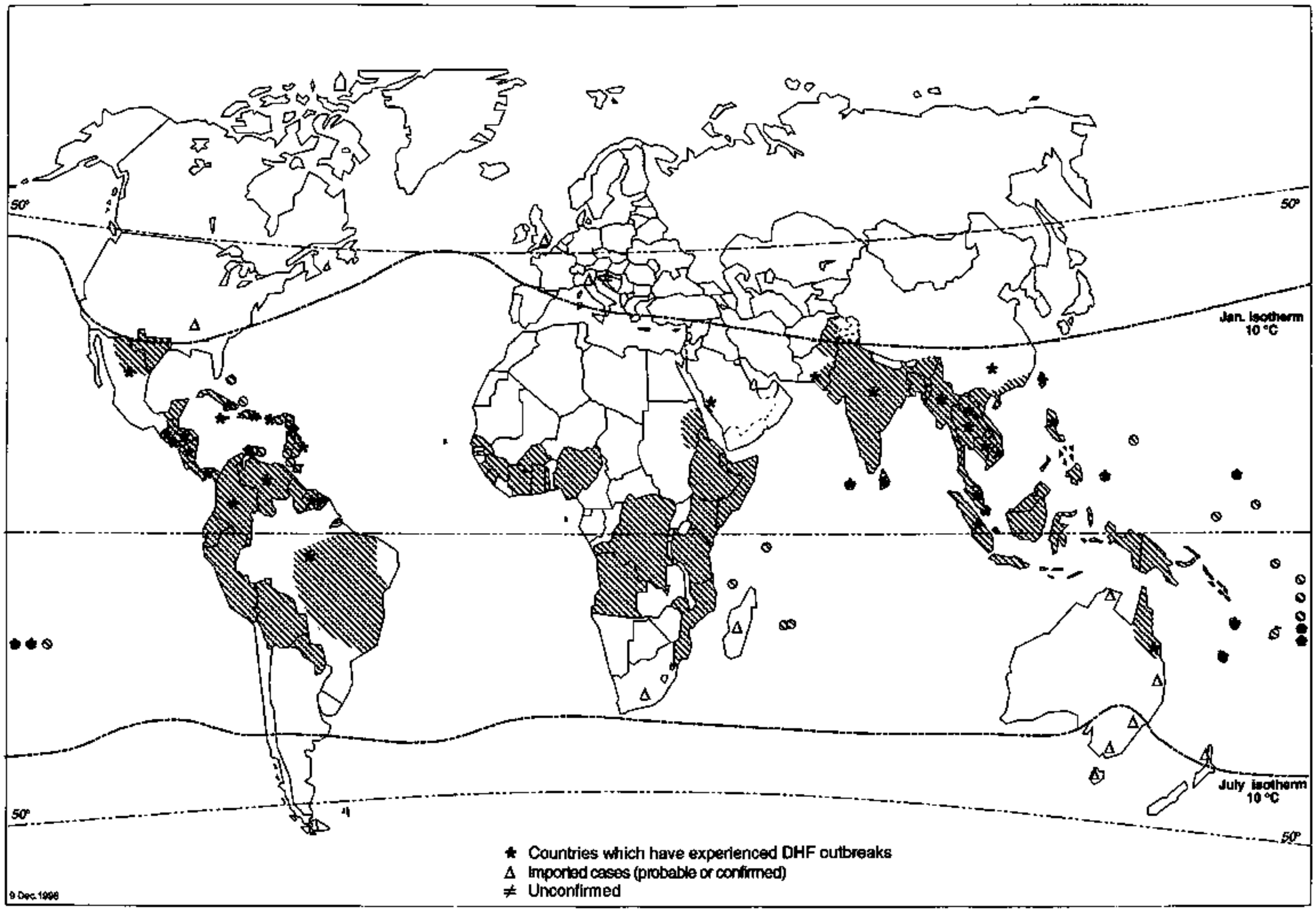


Fig. 1.25. Distribution of dengue and dengue haemorrhagic fever (DHF) outbreaks, 1975 - 1996 (© WHO).

WHO 94386 b/w

Two forms of the disease occur: dengue fever and dengue haemorrhagic fever.

Dengue fever occurs in explosive epidemics that mainly affect adults, sometimes with tens of thousands of cases, especially in urban areas. It is an acute febrile disease that starts suddenly and lasts for a week or more, causing intense headache, pain in joints and muscles, and rash. Infection rarely results in death. It occurs in most tropical countries and in some subtropical areas (Fig. 1.25). It can occur in rural and urban areas, if suitable vector mosquitos are present.

Dengue haemorrhagic fever is a severe illness that occurs in south-east Asia and has appeared relatively recently in the Americas and the South Pacific (Fig. 1.25), mainly affecting children. Infection starts with high fever, vomiting, headache, difficulty in breathing and pain in the abdomen. Signs of internal bleeding are common (Fig. 1.26). Dengue shock syndrome may develop as a result of loss of blood and lowered blood pressure. If treatment is not available, as many as 50% of patients with shock may die, but overall mortality from dengue haemorrhagic fever is usually in the range of 5 - 10%.

Prevention, treatment and control

No vaccines are available against dengue infections although work is in progress to develop one. There is no specific treatment for the disease, but patients with dengue shock syndrome can be treated by rapid administration of fluid and plasma and the monitoring of vital signs.

Fig. 1.26. Internal bleeding in dengue haemorrhagic fever may cause darkening of the skin of the face and hands. Children are most commonly affected.

The most effective preventive measures aim at reducing the population density of the vector, *Aedes aegypti*. Sustained control is achieved most economically by large-scale prevention of breeding, through removal or filling of breeding habitats in man-made and natural containers, the burning of organic waste, screening or fitting mosquito-proof lids to drinking-water storage containers, installing piped drinking-water supply, and, if other methods are not feasible or practical, applying safe and effective larvicides to breeding sites. Strategies for such source reduction by communities require extensive, long-term health education.

Also recommended is personal protection against daytime-biting mosquitos, including the use of protective clothing, repellents and house screening. In addition to the chemical methods commonly employed against biting mosquitos, such as the use of indoor space-spraying, daytime protection is obtainable from mosquito coils and mats, bednets, and air-conditioning.

In epidemic situations the same measures should be taken, but attempts should also be made to reduce populations of adult mosquitos rapidly by outdoor space-spraying with insecticides. Insecticidal sprays are usually applied to the parts of towns where abundant breeding sites are available, supporting large populations of *Aedes*. Space sprays can be applied with knapsack or hand-carried fogging machines and by truck- or aircraft-mounted machines. Residual wall spraying against *Aedes aegypti* is generally ineffective as this species normally rests indoors on surfaces that are not suitable for spraying, such as curtains and other fabrics. Stocks of insecticides should be kept for emergencies.

Viral encephalitis

Viral encephalitis is an acute inflammatory condition of the brain and spinal cord. A number of viruses cause the same signs and symptoms but with differing severities and rates of progress. Many infected people may have no symptoms. In mild cases there is fever and headache; severe cases are marked by high fever, headache, tremors, coma and spastic paralysis. Death is most frequent in infections with Japanese encephalitis and is also common in Murray Valley encephalitis and eastern equine encephalitis. Survivors are often left mentally retarded and with neurological disturbances.

Distribution and transmission

Some of these viruses are maintained in birds, especially herons, egrets, ibises and other species that live in or near marshes. The viruses are transmitted by mosquitos from the bird reservoir to other animals, such as horses and pigs, and humans. Infected horses may become very sick and die, as with Venezuelan equine encephalitis.

Japanese encephalitis occurs in China and south-east Asian countries (see Fig. 1.27); it formerly occurred in Japan. It is most common in rice-growing areas where *Culex tritaeniorhynchus* and related species transmit the virus from birds to pigs and humans. Mosquitos also transmit it from pigs to humans. Venezuelan equine encephalitis is found in South and Central America and southern USA. The western equine and St Louis encephalitis viruses occur in the USA and northern parts of South America. Eastern equine encephalitis occurs in eastern USA, South America, and in parts of Asia, Australasia and Europe.

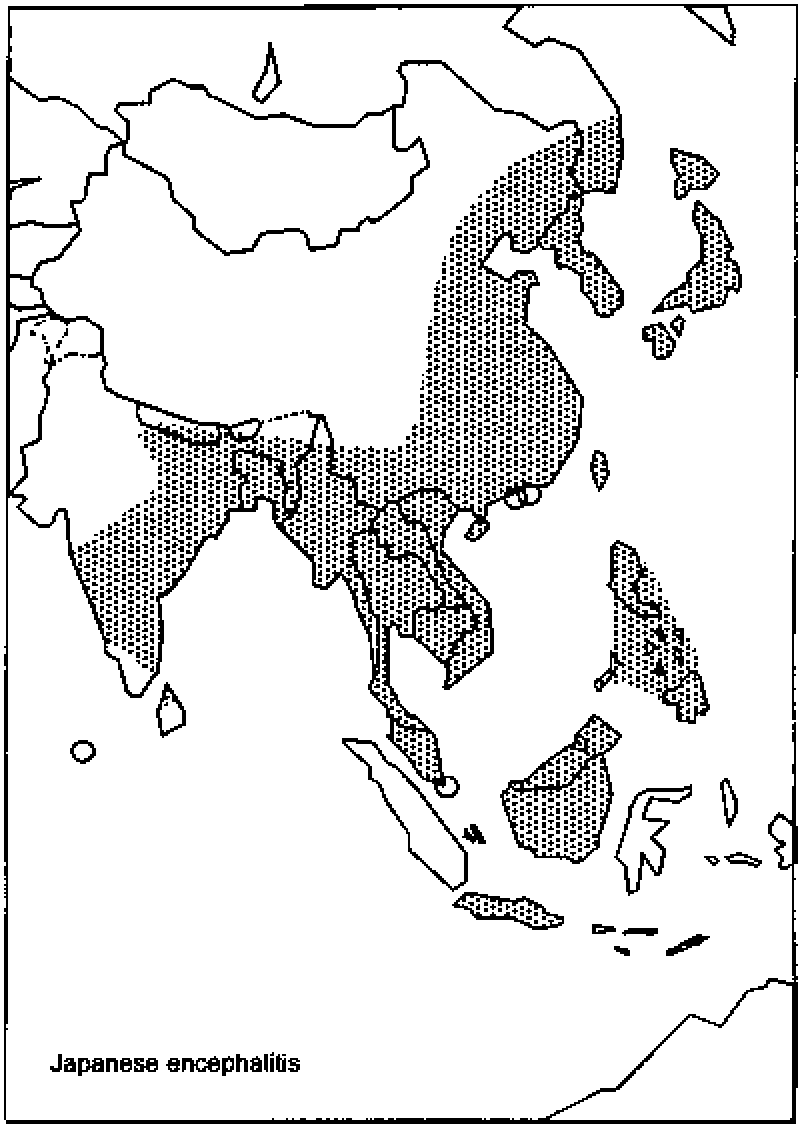


Fig. 1.27. Distribution of cases of Japanese encephalitis in southern and eastern Asia, 1995 (© WHO).

WHO 95476

Prevention, treatment and control

A vaccine against Japanese encephalitis is used to immunize children in some of the Asian countries in which the disease is endemic. A vaccine is also available against eastern equine and western equine encephalitis. No specific treatment exists for infected individuals.

Infections can be prevented by using protective clothing, repellents, house screening, mosquito nets, coils and mats, and by the avoidance of outdoor activities in the evening. The spraying of houses and animal shelters in rural areas to control the *Culex* vectors of Japanese encephalitis is generally ineffective because of the outdoor biting and resting habits of the vector species (*5*). In some areas control is possible by measures that prevent breeding in rice fields and irrigation systems. Outdoor space spraying with insecticides can be carried out where epidemics occur. In endemic areas it is recommended that domestic animals be housed away from human habitations. This applies especially to pigs in areas where Japanese encephalitis is endemic.

Other viral diseases

Many other viral diseases are transmitted to humans by mosquitos, among them chikungunya virus disease and Rift Valley fever in irrigated areas of East Africa and India, where large-scale epidemics occur. Ross River disease occurs in parts of Australia and in some Pacific islands. It often causes arthritis of the joints of the hands and feet for a limited period.

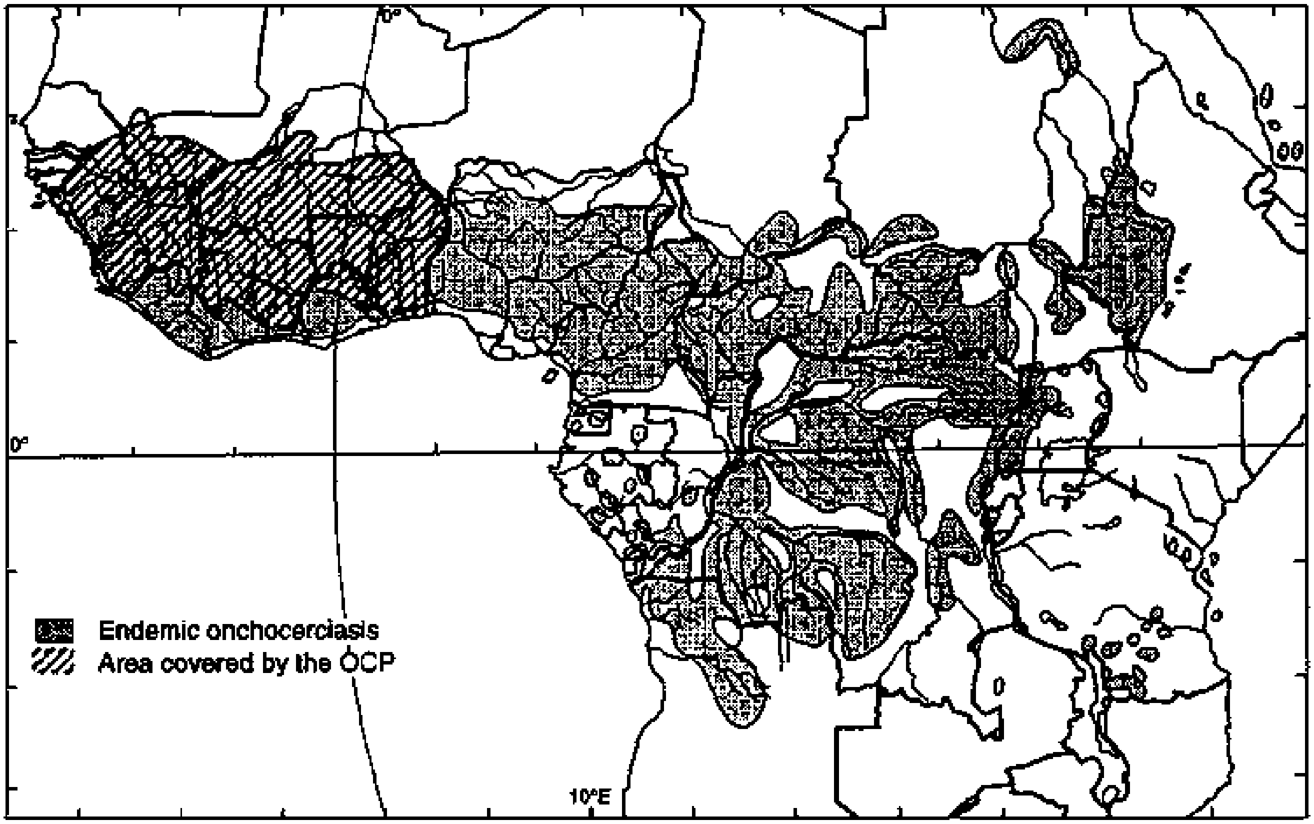
No vaccines or specific treatments exist for these diseases. Prevention and control are possible by taking appropriate measures against the mosquito vectors.

Onchocerciasis (river blindness)

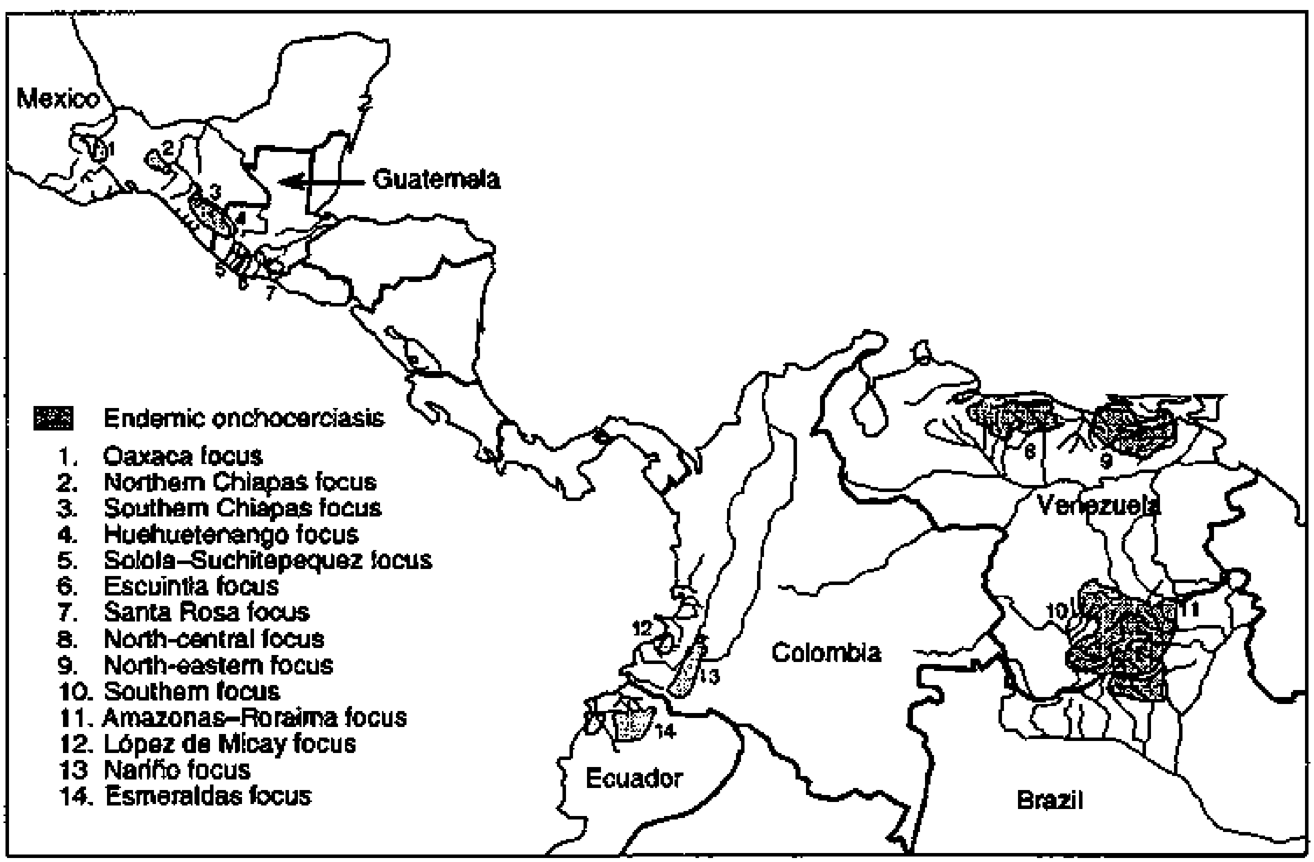
Onchocerciasis is caused by a parasitic filarial worm, *Onchocerca volvulus*. It is transmitted from person to person by *Simulium* blackflies. Infection can cause severe itching of the skin, eye lesions and blindness. The disease has a focal distribution and occurs throughout West and Central Africa and parts of East Africa. The most heavily infected areas are savanna regions in West Africa. Transmission also occurs in localized areas in Yemen and in Central and South America. In 1995 it was estimated that almost 18 million people were infected, of whom 268000 were blind; in addition, a further 500000 were severely visually disabled (Fig. 1.28).

Transmission

Blackflies are the only vectors. Embryos of *Onchocerca* (microfilariae) are ingested during feeding. The microfilariae develop into infective larvae in the body of the fly after 6 - 10 days and are then transmitted to humans during feeding and develop into adult worms (Fig. 1.29). The female worms can live in the human body for up to 12 years and produce millions of microfilariae, which migrate to the skin where they can be ingested by biting blackflies. Transmission is most common near the fast-flowing rivers or streams where the blackflies breed and where they may attack humans in large numbers. Transmission does not take place below 18 °C and the disease occurs only in the tropics.



0°
0°
10°E
Endemic onchocerciasis
Area covered by the OCP



Mexico
Guatemala
Venezuela
Colombia
Ecuador
Brazil
Endemic onchocerciasis
1. Oaxaca focus
2. Northern Chiapas focus
3. Southern Chiapas focus
4. Huehuetenango focus
5. Solola–Suchitepequez focus
6. Escuintla focus
7. Santa Rosa focus
8. North-central focus
9. North-eastern focus
10. Southern focus
11. Amazonas–Roraima focus
12. López de Micay focus
13 Nariño focus
14. Esmeraldas focus

Fig. 1.28. Geographical distribution of onchocerciasis, 1995 (© WHO).

WHO 96168/WHO 96168

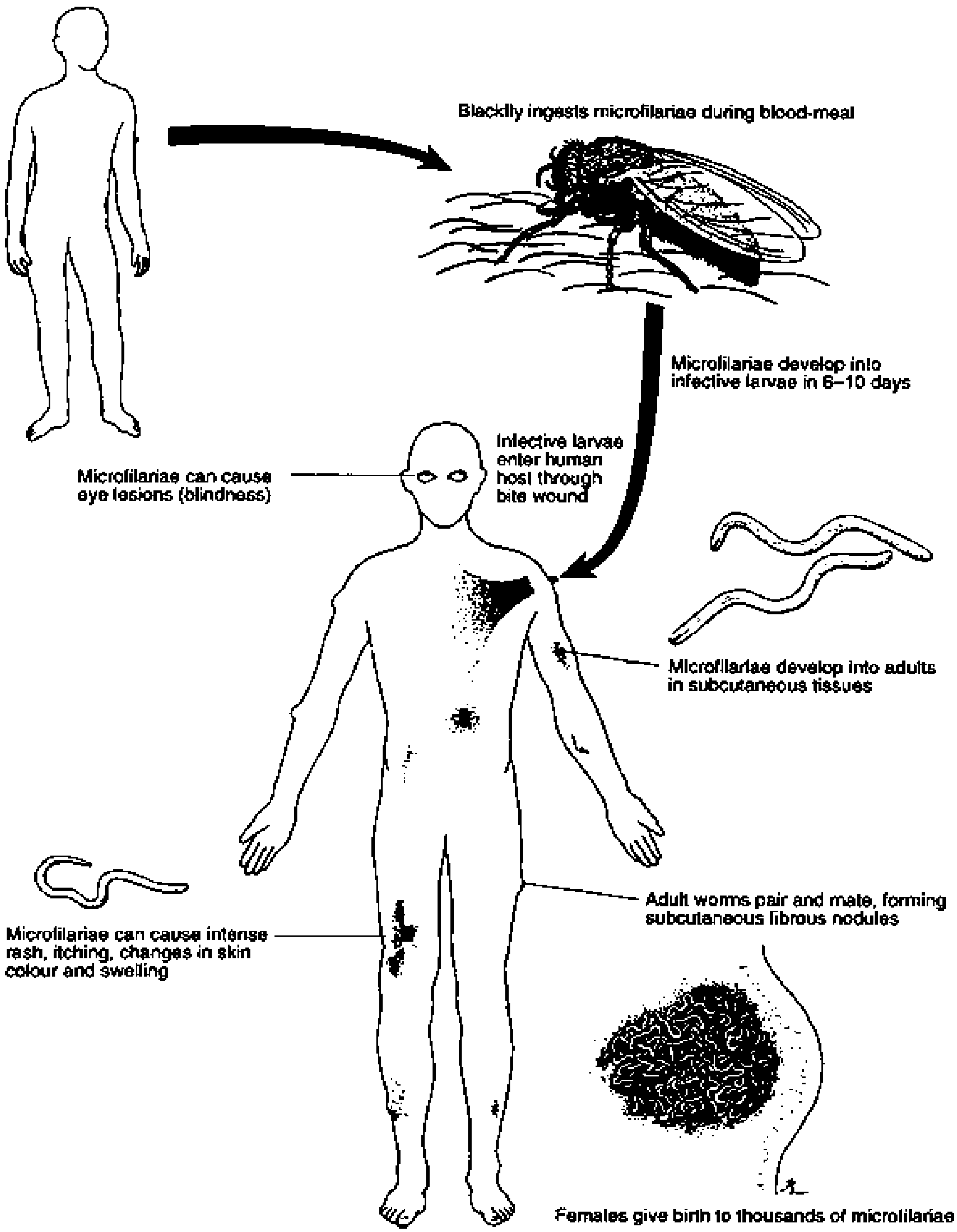


Fig. 1.29. Life cycle of *Onchocerca volvulus* (by Taina Litwak for the United States Agency for International Development's VBC Project).

Clinical symptoms

The adult worms develop in nodules below the skin which range in diameter from a few millimetres to several centimetres. They are clustered in places where the skin closely overlies the bones. Most of the symptoms are caused by the microfilariae, which are released from the nodules and migrate to the skin and eyes. The most common complaint is itching.

In long-lasting infections the affected skin becomes atrophic and thin. Permanent damage to the eyes, including blindness - the most serious effect of the disease in terms of both individual well-being and rural economics - develops after prolonged heavy infection over several years. Travellers to affected areas are unlikely to develop serious symptoms should they become infected.

Fig. 1.30. Aerial application of insecticide to *Simulium* breeding sites in a river.

Treatment, prevention and control

The prevention of infection is only possible through blackfly control. Ivermectin, a newly developed drug, kills the microfilariae but not the adult worms. However, annual re-treatment with one tablet is sufficient to prevent blindness. It is now being used on a large scale to treat infected people and to stop further development of the disease.

In the eleven West African countries covered by the Onchocerciasis Control Programme (see box) the control of the disease is based on a combination of vector control and the distribution of ivermectin. In all other endemic countries in Africa and Latin America, and in Yemen, control is limited to the periodic distribution of ivermectin.

The Onchocerciasis Control Programme

In West Africa the Onchocerciasis Control Programme, a joint programme of WHO, UNDP, the World Bank, donor countries and the countries of West Africa, was initiated in 1974. It aims to reduce blackfly populations to low levels over a sufficiently long period (up to 20 years) to interrupt transmission of the parasite and to allow the adult worms, which can live in humans for up to 12 years, to die out completely. The programme is based on large-scale aerial applications of insecticides and, in recent years, the distribution of the drug ivermectin (*6*, *7*). The application of insecticides to streams and rivers in order to destroy the larvae is the only practical method of controlling the blackfly vectors (Fig. 1.30). The application of an insecticide to a selected breeding site usually also results in the killing of larvae in breeding sites located up to 10 km downstream. To avoid damaging the environment and wasting material, the insecticides employed are largely specific for blackfly larvae and are applied and monitored under careful supervision. Among the commonly used larvicides are temephos, phoxim and *Bacillus thuringiensis* H-14. The products are rotated to reduce the problem of the development of insecticide resistance in the blackfly populations (*8*, *9*).

One of the reasons for the large-scale applications to extensive networks of watercourses is the ability of the blackflies to fly with the wind over distances of up to several hundreds of kilometres. Localized control of breeding sites would not be sufficient because of the likelihood of reinvasion from outside areas.

Leishmaniasis

Leishmaniasis is caused by protozoan parasites of the genus *Leishmania*, and occurs in both humans and animals. In 1996, it was estimated that some 12 million people were infected and 350 million were at risk of acquiring infection.

Visceral leishmaniasis, also known in the Indian subcontinent by its Hindi name, kala-azar, is caused by *Leishmania donovani, L. infantum* or *L. chagasi*; it is a disease of the internal organs and is often fatal if left untreated. It is endemic in East Africa, the Indian subcontinent and South America, and occurs sporadically in China, the Mediterranean region, south-west Asia and the countries of the southern part of the former USSR (Fig. 1.31a).

Mucocutaneous leishmaniasis, also known in South America as espundia, is caused mainly by *Leishmania braziliensis*; it is a disease of the skin and mucosal tissues in the nose and mouth, and can lead to gross deformities. It occurs in Central and South America; oronasal leishmaniasis due to other *Leishmania* species has been recorded in Ethiopia and Sudan (Fig. 1.31b).

Distribution of leishmaniasis:

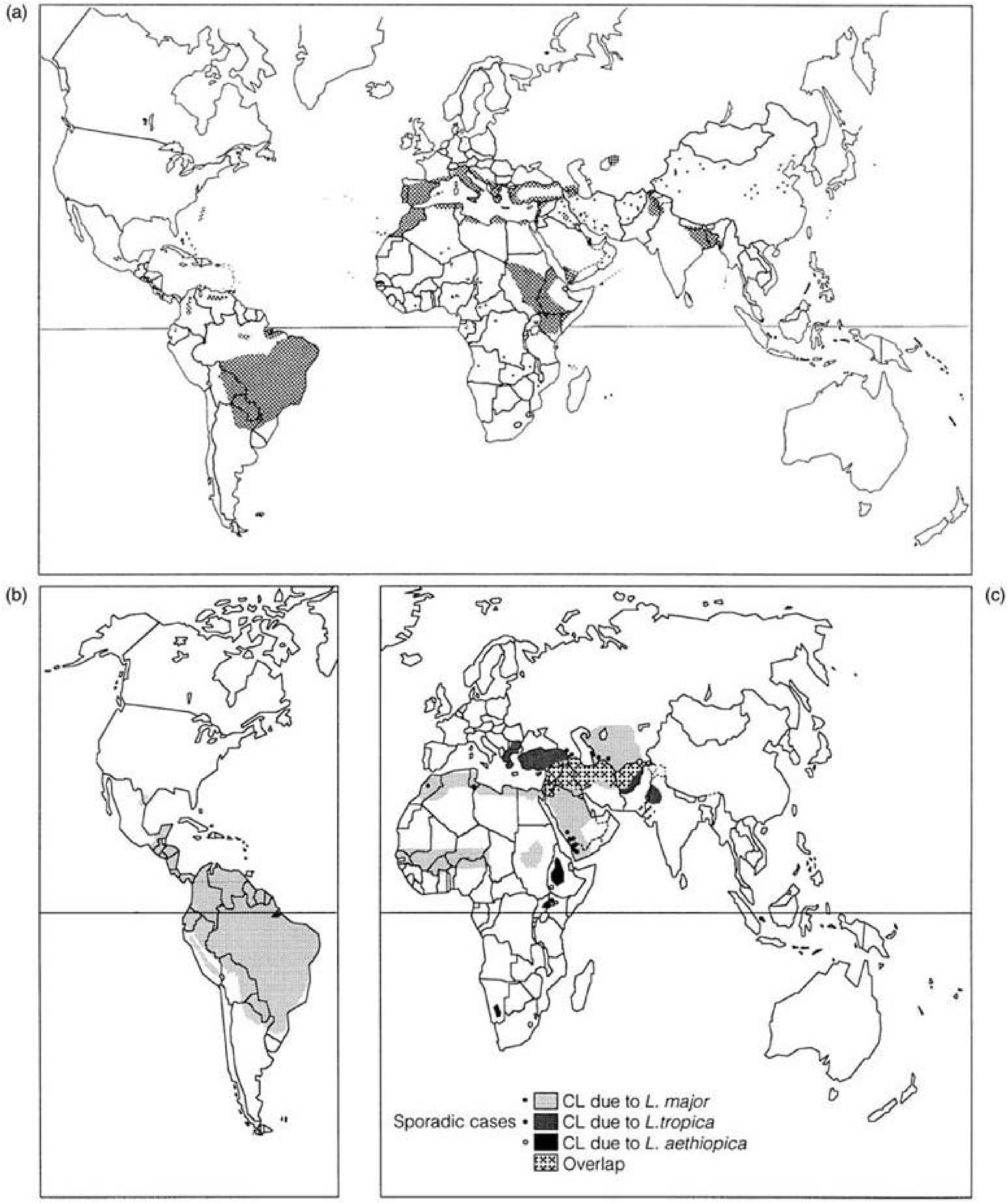


Fig. 1.31. (a) Visceral leishmaniasis in the Old and New World, 1989; (b) Cutaneous

and mucocutaneous leishmaniasis in the New World, 1996; (c) Cutaneous leishmaniasis in the Old World, 1996 (© WHO).

WHO 89983/WHO 96008/WHO 96009

Cutaneous leishmaniasis is known under a variety of common names such as oriental sore, clou de Biskra, Aleppo boil, Bahia ulcer and chiclero's ulcer. It is caused by, among other species, *Leishmania major, L. tropica* and *L. aethiopica*, and species of the *braziliensis* and *mexicana* complexes, and results in ulcers of the skin. It is the most common form of leishmaniasis and occurs in Africa, South America, the Indian subcontinent, south-west Asia, the Mediterranean region and the countries of the southern part of the former USSR (Figs 1.31b and1.31c).

Transmission

Most forms of leishmaniasis are primarily infections of small mammals. Humans are often infected by sandflies which previously fed on infected animals (Fig. 1.32). The importance of animals as reservoirs of parasites varies from place to place and transmission from human to human also occurs. The sandfly species involved in transmission also vary from one place to another and often differ in their ecology and behaviour.

In South America the persons at highest risk of infection with cutaneous or mucocutaneous leishmaniasis are those entering forests, such as woodcutters, collectors of rubber and other forest products, hunters, construction workers and farmers. An elevated risk occurs in settlements close to dense forests (*10*).

In the Indian subcontinent, indoor and peridomestic transmission is more common since visceral leishmaniasis is anthroponotic and the vector is strictly peridomestic. In Africa, there is a great variety of epidemiological situations. For example, in East Africa the risk of visceral leishmaniasis infection is increased among men who often sit in communal groups around termite hills, and there is a heightened risk of cutaneous leishmaniasis infection among boys who drive cattle into caves to find shelter and salt licks (R. Killick-Kendrick, personal communication).

The risk of being infected is higher for people who sleep outdoors or have outdoor activities at night. An increased risk also occurs in places where there are infected rodents or other host animals.

Clinical symptoms

Where visceral leishmaniasis (kala-azar) is endemic, children are most affected except in southern Europe and China, and twice as many males are affected as females. The disease starts slowly with fever, malaise, loss of weight and, in many cases, cough and diarrhoea. A major clinical sign is enlargement of the spleen and liver (Fig. 1.33); lymphadenopathy may be present. Kala-azar may cause darkening of the skin of the face, hands, feet and abdomen in India. Other signs are similar to those of malnutrition, such as oedema and changes in skin and hair. The disease may follow a more severe and acute course in people from areas without kala-azar who have no immunity.

In cutaneous leishmaniasis the symptoms differ between and within regions, depending on the species of parasite and the immune response of the patient. A typical ulcer starts as a nodule at the site of the sandfly bite; a crust develops in the middle which, if it falls away, exposes the ulcer (Fig. 1.34). The ulcer heals gradually and leaves a permanent depressed scar different in colour from the surrounding skin. Depending on the parasite species, healing takes place spontaneously in periods ranging from two months to several years. Some types do not heal without treatment and may develop into mucocutaneous leishmaniasis. Sometimes the disease spreads via the lymphatic system and causes ulcers all over the body.

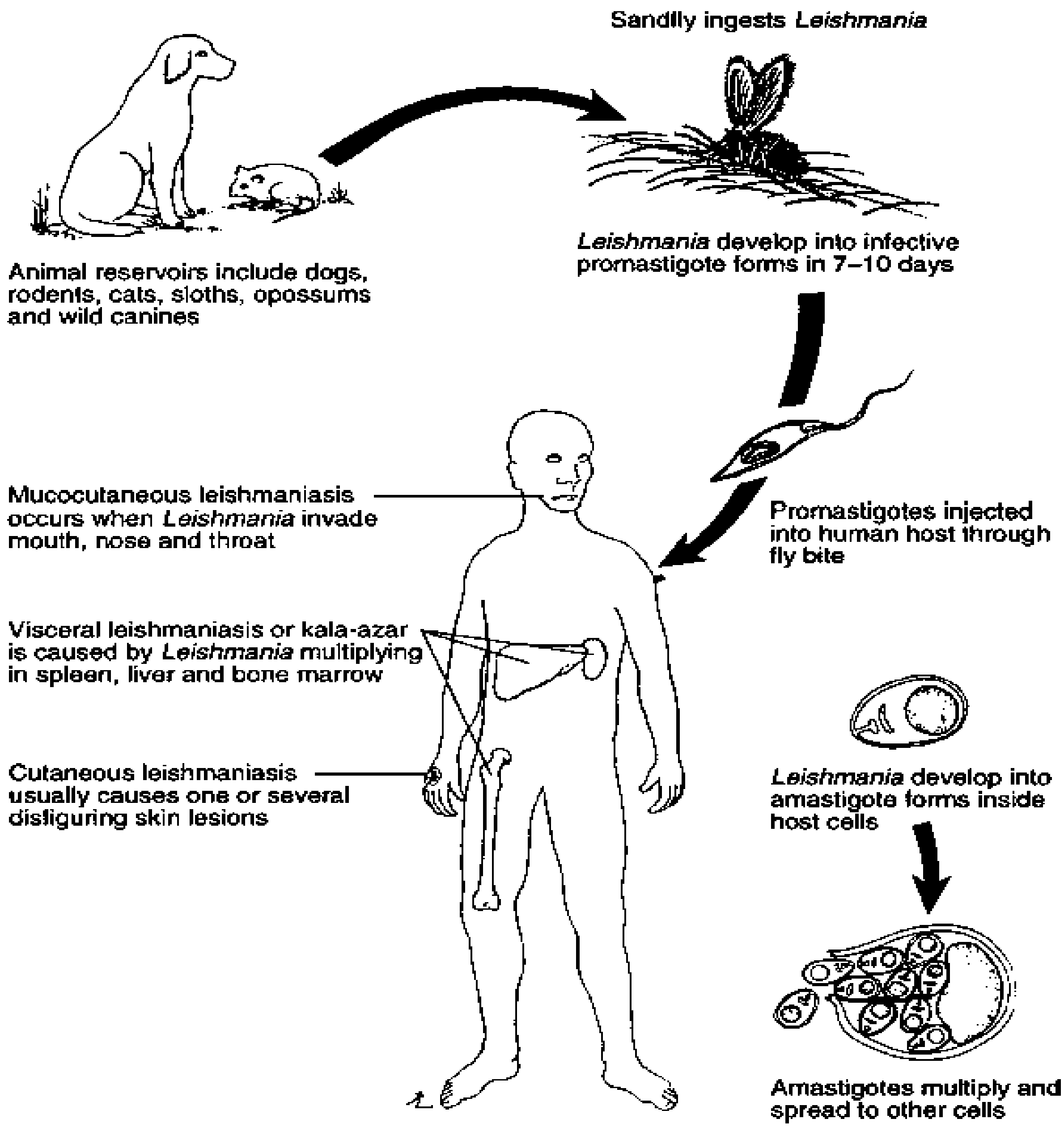


Fig. 1.32. Life cycle of *Leishmania* (by Taina Litwak for the United States Agency for International Development's VBC Project).

The first symptoms of mucocutaneous leishmaniasis are similar to those of cutaneous leishmaniasis but the parasites may spread to the mucosa in the oronasal and pharyngeal cavity. The soft tissues and cartilage in these areas are then progressively destroyed by ulcers and erosion (Fig. 1.35). Swelling of the lips and nose may produce a so-called “tapir nose”. Mutilations are severe and occasionally result in death due to malnutrition and bronchopneumonia.

Fig. 1.33. A typical clinical sign of visceral leishmaniasis is enlargement of the spleen and liver.

Fig. 1.34. Cutaneous leishmaniasis may typically cause ulcers which, after healing, leave permanent depressed scars.

Treatment

Simple cutaneous leishmaniasis usually heals without treatment and renders the person immune to other infections with the same parasite species. For this reason, infants have sometimes deliberately been infected on their back or buttocks to protect them from other infections which might have caused ugly scars on the face.

Fig. 1.35. Mucocutaneous leishmaniasis may cause severe mutilations of the face through progressive destruction of soft tissues in the cavities of the mouth and nose.

The other forms of leishmaniasis are difficult to treat and usually require a long course of pentavalent antimony - meglumine antimoniate or sodium stibogluconate. The injections are frequent and painful and although treatment is usually well tolerated, mild side-effects can arise, including anorexia, vomiting, nausea, malaise, myalgia and headache. More rarely, hepatotoxicity and cardiotoxicity produce more serious side-effects. The second-line drugs are amphotericin B and pentamidine.

Prevention and control

Individuals can prevent infection by avoiding being bitten by sandflies. It is recommended that personal protection measures be taken, that fine-mesh or insecticide-treated bednets be used and that house improvements be carried out. Self-protection is sometimes possible by avoiding places where sandflies are known to rest or breed. In dense forests it is recommended not to stand between buttress roots of large trees (Fig. 1.36). New settlements in forests should preferably be surrounded by a forest-free belt about 300 - 400 metres in width (*11*, *12*).

To reduce the transmission of leishmaniasis, approaches adapted to the epidemiological circumstances have to be put into effect, such as the detection and treatment of patients and the control of vectors or reservoir hosts. Control measures also depend on the habits of local vector species and, if applicable, the habits of the reservoir animals. Where the parasite reservoir is exclusively in humans, outbreaks can be controlled by case detection and rapid treatment.

Indoor-resting sandflies can be effectively controlled by spraying the inside surfaces of walls and the interiors and exteriors of doorways, windows and other openings with a residual insecticide. Only in a few areas have insecticides been sprayed against leishmaniasis vectors alone. In most cases, the control of malaria mosquitos has been the main priority, that of sandflies being coincidental. In the case of epidemic outbreaks, ultra-low-volume insecticide space-spraying in and around houses is worthy of consideration.

With regard to the control of animal reservoirs, it should be noted that certain development activities can cause a reduction in the occurrence of *Leishmania* when alteration of the environment makes it unsuitable to the wild host animals that live in forests. In Ethiopia, control measures were carried out against the rock hyrax, a wild animal reservoir of leishmaniasis. The most important domestic reservoir animal is the dog, but horses, donkeys and mules have also been reported as domestic reservoirs for cutaneous leishmaniasis in the Americas. In some areas, for instance Brazil, China, the Mediterranean region and the former USSR, measures have been taken to destroy infected dogs and other reservoir animals. In the former USSR the main control programme was against the great gerbil, *Rhombomys opimus* (*13*).

Mansonellosis

Mansonellosis is caused by infection with one of the human filarial parasites belonging to the genus *Mansonella. Mansonella ozzardi* occurs in Mexico, Panama, the Caribbean and South America. It is most prevalent among American Indians and is transmitted by biting midges of the genus *Culicoides* and by blackflies. It is generally considered harmless but some complaints, such as pain in the joints, have been reported. *Mansonella perstans* occurs in parts of South America and Africa, *M. streptocerca* in some West and Central African countries. Both parasites are transmitted by *Culicoides* biting midges.

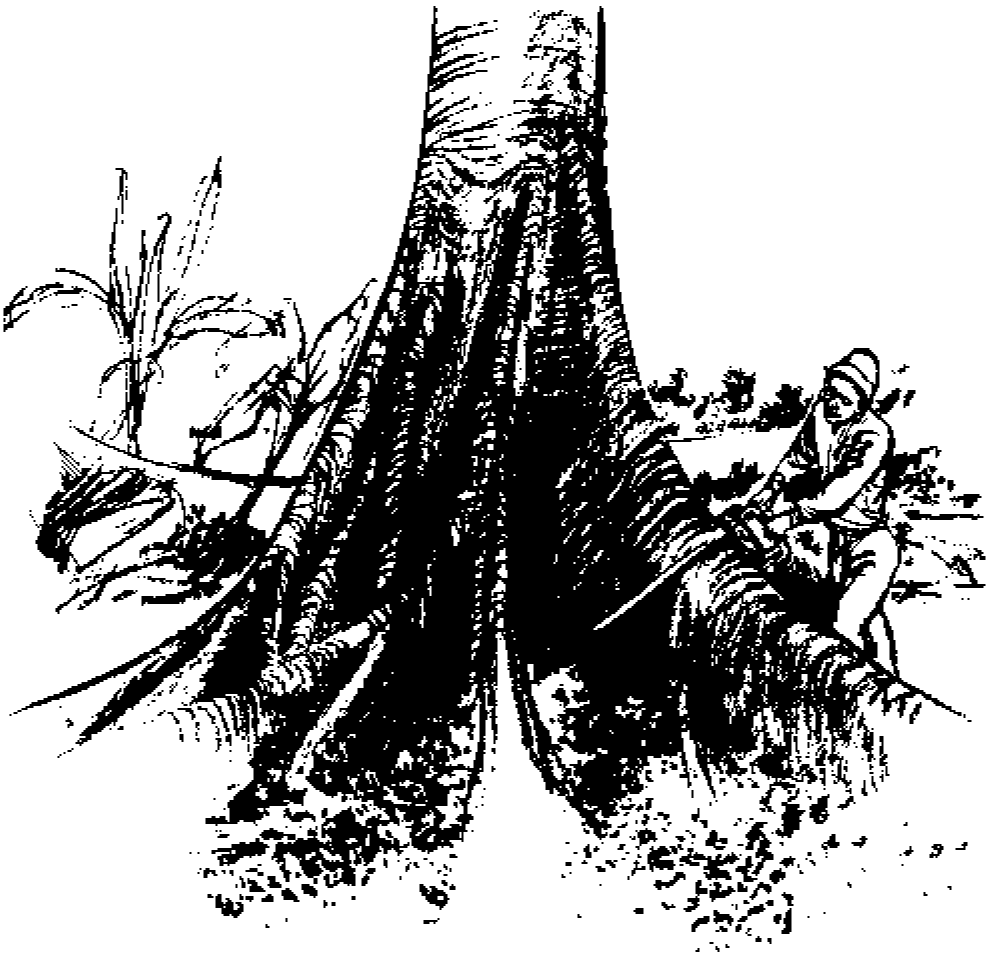


Fig. 1.36. In dense tropical forests of South America, sandflies often rest and breed in humid soil between the buttress roots of large trees.

The adult worms live in body cavities and in the mesentery where they seem to cause little or no harm to the human host. The larvae occur in the blood and skin.

Infections with these parasites can be treated with diethylcarbamazine. Most cases remain untreated because infected persons rarely complain of symptoms.

Loiasis

This disease is caused by the filarial parasite *Loa loa*. It is transmitted by deerflies of the genus *Chrysops* and occurs only in woods and forests in West and Central Africa, from Benin to Uganda and southern Sudan.

Its life cycle resembles that of *Onchocerca volvulus* (see Fig. 1.29). The adult worm lives in tissues under the skin. Migrations of the worms under the skin may cause a pricking, itching sensation. Infection sometimes causes swelling of various parts of the body. The larvae occur in the bloodstream and are picked up by biting tabanids.

Treatment is possible with diethylcarbamazine and ivermectin.

Tularaemia

This is a bacterial disease transmitted by the bites of deerflies (*Chrysops*) and hard ticks. For more information see Chapter 4.

Control measures

Selecting the most appropriate control measures

Table 1.2 shows where and when the different groups of biting Diptera are active. Personal protection measures, such as repellents and protective clothing, are effective against all of them. Bednets are effective against Diptera that bite at night. Measures to make houses and shelters insect-proof work against species that enter houses to feed and rest. Mosquitos can usually be prevented from breeding in and around houses by simple, long-lasting measures. However, some biting may continue because of mosquitos flying in from adjacent plots of land where they still breed. Cooperation between neighbours is therefore important in order to achieve good control.

The self-protection methods can be selected without knowing exactly which species one wishes to control. They are mainly used to protect individuals, families or small groups of people living together. Methods such as the use of insecticide-treated bednets, house improvement and the prevention of breeding may also be used to reduce diseases in a community if the majority of the people participate.

The methods for disease control in the community are usually implemented on a large scale and require at least some support and participation by a local health care organization. Health workers with experience in the control of vector-borne disease should be consulted for the selection and implementation of the most appropriate control strategy for the local situation.

Table 1.2. Selection of control measures for biting Diptera[a]

Pest/vector	Indoor/outdoor biting (I/O)	Day/night biting (D/N)	Self-protection					Disease control in the community			
			Personal protection		Insectproofing of houses	Prevention of breeding in and around houses	Other control methods (adults)	Residual wall-spraying	Space-spraying[b]	Prevention of breeding in field	Other control methods (adults)
			Repellents, clothing	Bednets							
Anopheles	I/O	N	+ +	+ +	+ +	+/-[c]	+/-[d]	+	+/-	+	+/-[d]

Culex	I/O	N	+ +	+ +	+ +	+ +[e]	+/-[f]	+/-	+/-	+/-[g]	+/-[f]
Aedes	I/O	D	+ +	+/-	+ +	+ +	-	+/-	+	+/-[h]	-
Mansonia	I/O	N	+ +	+ +	+ +	-	-	-	-	+/-[i]	-
Blackflies	O	D	+ +	-	-	-	-	-	-	+[j]	-
Sandflies	I/O	D/N	+ +	+ +	+ +	-	+/-[k]	+/-	+/-	+/-	+/-[k]
Midges	I/O[l]	D/N	+ +	+ +	+ +	-	-	-	-	+/-[m]	-
Horseflies	O	D	+[n]	-	-	-	-	-	-	-	-
Stable flies	O	D	+ +	-	-	+/-	+[o]	-	-	-	+[o]
Tsetse flies[p]	O	D	+	-	-	-	+[q]	-	+/-	-	+[q]

[a] + + = effective; + = usually effective; +/- = sometimes effective; - = not effective.

[b] In the case of epidemic outbreaks, ultra-low-volume insecticide space-spraying can be considered.

[c] *Anopheles* does not usually breed near houses in urban areas, with the exception of *A. stephensi* in southern Asia. In Africa, malaria transmission occurs in the semiurban fringes of cities with prevailing rural conditions.

[d] It may be possible to obtain some additional protection by diverting mosquitos to domestic animals (see p. 105).

[e] Against *Culex quinquefasciatus.*

[f] Siting animal shelters far away from rice fields was effective in Japan (*14*).

[g] Control of the larvae of *Culex tritaeniorhynchus* in rice fields in Asia is difficult but may sometimes be achieved by intermittent irrigation, the use of larvivorous fish, and the application of bacterial larvicides.

[h] To control pest mosquitos breeding in rural areas, such as tidal salt marshes, granular insecticides are sometimes used which only release the active agent after flooding with water, which coincides with the hatching of the eggs. Other methods include the control of water levels and the improvement of irrigation and drainage systems.

[i] Sometimes by removing or destroying the aquatic vegetation to which the larval and pupal stages are attached (see p. 18).

[j] By application of larvicides to streams and rivers (see p. 45).

[k] By avoiding places where sandflies are known to rest and breed.

[l] Sometimes biting midges enter houses or tents.

[m] Where feasible the draining or filling of marshy areas is highly effective but is often too costly. In some cases, aerial spraying of such places with insecticides provides effective but temporary control by killing the larvae.

[n] Protection from bites is possible with thick clothing. Commonly available repellents are moderately effective against tabanids.

[o] Methods that reduce or stop feeding on domestic animals not only benefit them but also the people living near their quarters. Commercially available insecticide-impregnated eartags for animals are highly effective against *Stomoxys calcitrans* for between one and two months.

[p] See Chapter 2.

[q] Includes the use of traps and screens and spraying of daytime resting places of the flies with residual insecticides.

Personal protection

Personal protection methods, used by individuals or small groups of people to protect themselves from biting insects and the diseases they may carry, act by preventing contact between the human body and the insects. The equipment is small, portable and simple to use. The methods may offer significant protection against infection to individuals and sometimes have an impact on disease transmission in communities when a large proportion of people use them.

Repellents

Repellents are among the most commonly used methods to prevent mosquitos and other blood-sucking pests from biting. They are applied directly to the skin or to clothing and other fabrics such as bednets and anti-mosquito screens. Repellents evaporate much more quickly than most insecticides. Insecticides last longer and act by killing or knocking down insects after contact, whereas most repellents act by preventing human - insect contact and do not knock down or kill. The duration of protection by a repellent applied to skin may range from 15 minutes to 10 hours; on clothing and other fabrics the effect lasts much longer. The effectiveness and duration depend on the type of repellent (active ingredients and formulation; see Fig. 1.37), the mode of application, local conditions (temperature, humidity, wind), the attractiveness of individual people to insects, loss due to removal by perspiration and abrasion (*15 - 17*) and the sensitivity of the insects to repellents, each species having its own specific sensitivity (*18 - 20*). The biting density also plays an important role: the more mosquitos there are, the more one is likely to be bitten.

Under certain conditions the user may be completely protected while in other situations the protection is limited. People working or travelling in humid tropical forests are likely to need repeated application of repellents to the skin because of quick removal by perspiration (*21*). Because of the short period of action, repellents are mostly applied when insects start biting. For mosquitos this is very often around sunset.

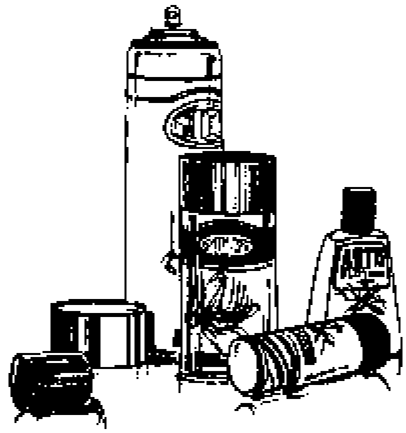


Fig. 1.37. Repellents are available as sprays, lotions, creams, sticks and wipe-on applicators or tissues.

When and where to use

Repellents are valuable for people in situations where other protective measures do not work, are impractical or are prohibited: people who must be outdoors at night; plantation workers at risk during daytime; people crossing or approaching areas such as tundras, swamps, grasslands or forests infested with mosquitos or other biting insects; and so on. Repellents may be preferred for use indoors if the screening of a house is impossible or considered unpleasant because it reduces ventilation too much in hot climates. Travellers often favour repellents as they are easily transportable and they can be applied anywhere at any time. Repellents can play an important role in combination with other methods for the control of mosquitos or biting flies; for example their use in the early evening can be followed by the use of bednets against indoor night-biting mosquitos.

Repellents are widely available but their retail price may be too high for daily use by many people. The various types differ in effectiveness according to their composition.

Instructions for use

Whatever repellent is used, it should be applied sparingly to all exposed skin, especially the neck, wrists and ankles. The surroundings of the eyes or mucous membranes (nose, mouth) should not be treated. Repellents should not be sprayed on the face; instead they can be applied by spraying on to the hands (Fig. 1.38) and then rubbing on to the less sensitive parts of the face as necessary. If an allergic skin reaction is observed the treated skin should be washed with water and a physician consulted and shown the can or other packing material (Fig. 1.39). A repellent can be checked for adverse skin reactions by applying a small quantity to the back of the hand.

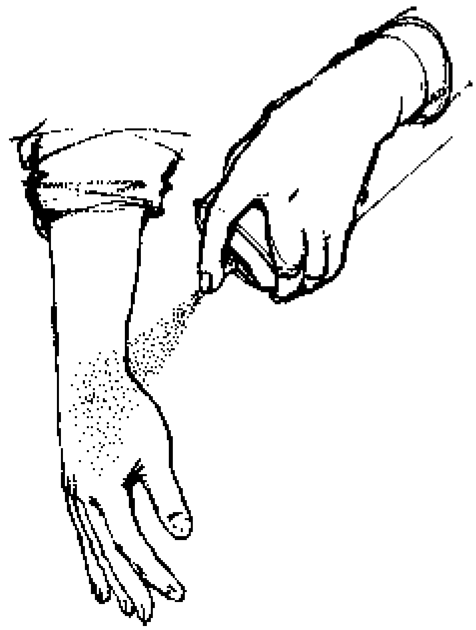


Fig. 1.38. Spray cans are used to apply repellent to exposed body parts.

Types of repellent

Traditional or natural repellents

Various substances and methods of application have been used since ancient times to repel blood-sucking insects (*22*). Smoke from an open fire repels insects, especially in still air or a poorly ventilated dwelling. The repellent effect of smoke may be increased by burning certain materials such as aromatic wood containing resins or various types of plant. In southern India, leaves of *Vitex negundo* ("nochi") are burned to repel mosquitos from houses.

The oils of some plants, such as citronella, are repellent when applied directly to the skin or clothing but their protective effect is very brief. It has sometimes been prolonged by mixing the volatile repellent with animal fat or oil to reduce the rate of evaporation. Many traditional repellents have the disadvantages that:

- they last a very short time;
- they are unpleasant to use (strong odours, irritating);
- they may have unhealthy side-effects (e.g. smoke).

However, their advantages are that:

- they are easily available;
- they are locally known and acceptable;
- they are inexpensive.

In this manual it is impossible to mention all the locally used traditional repellent substances and their application methods. Many of these substances have never been tested by scientists and their effectiveness remains to be confirmed.

Some plant products used as repellents which are safe for humans

Citronella

Oil from the citronella plant is widely used as a repellent. Industrially produced citronella is an active ingredient in some commercial repellents. When freshly applied to human skin, citronella is about as effective in repelling some biting insects as the chemical repellents, but for only about an hour.

Neem tree

In Africa, Asia and Latin America, leaves of the neem tree (*Azidarachta indica*) are sometimes burnt, producing an unpleasant odour, or hung dried inside houses. Some people believe that neem trees near a house keep mosquitos away but there is no scientific evidence of this. Extracts of neem seeds are used as agricultural insecticides.

Aromatic trees

The wood or the extracted resin of certain aromatic trees is sometimes burnt as a mosquito repellent. In some African countries such wood is sold in local markets (*23*).

Modern repellents for application to the skin

During the latter half of the twentieth century, several synthetic repellents have been produced which are long-lasting, nontoxic, cosmetically acceptable on the skin, and effective against a wide variety of insects. The most successful substances for skin application, developed in the first half of this century, were dimethyl phthalate, indalone and ethyl hexanediol. These substances are still among the active ingredients of some commercial repellents.

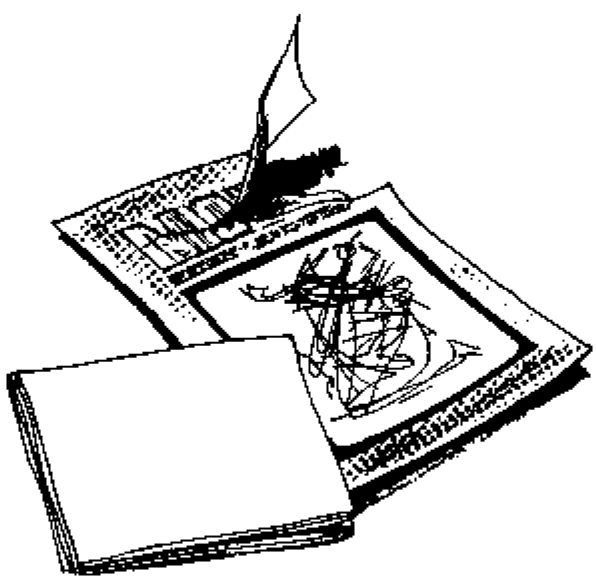


Fig. 1.39. A repellent-impregnated tissue taken out of its airtight package. The tissue is saturated in a mixture of deet and alcohol. It is used for wipe-on application.

A breakthrough came in 1954 with the discovery of *N*,*N*-diethyl-3-toluamide or deet, a colourless, oily liquid with a slight odour. It is still the best available product, repelling a wide variety of insects, ticks and mites and generally lasting longer than the other repellents (*18* - *20*, *24* - *27*). Deet is also effective against blood-sucking terrestrial leeches (*28*, *29*).

Deet is available as a pure liquid and in 5 - 90% solutions. To make deet and other repellents more convenient to apply and cosmetically attractive, they are often prepared as lotions, creams, foams, solid waxes (sticks) or spray-on preparations in pressurized containers. The repellents are often mixed with an oily or alcoholic base and a pleasant smelling perfume. The mixtures are spread, wiped or sprayed onto the exposed skin.

In some mixtures the base material (oils, silicones, polymers) reduces the evaporation rate of the repellent, thus extending the duration of efficacy (*15* - *17*). In some formulations of deet the repellent effect may last up to 12 hours, although 4 - 6 hours is more common. A disadvantage of some extended-duration formulations is that they may feel sticky when applied to the skin; this does not happen with an ethanol solution of deet.

Allergic or other serious reactions to deet, such as the development of rash, have rarely been reported (*30* - *32*). The compound is considered safe for adults, except following prolonged exposure to high concentrations. Since children appear more sensitive, it is recommended that their skin exposure be kept to a minimum whenever possible and that deet should be applied to their clothing, rather than to their skin (*33*). Some plastic materials (e.g., pens, watch faces, spectacle frames, car seat covers) and painted surfaces may be dissolved or damaged by deet.

Data from India suggest that *N,N*-diethylphenylacetamide (DEPA) is as effective as deet but less expensive (*34*). Citronella is often used because it is inexpensive and some people think that it has a more pleasant smell. Less commonly available are dimethyl phthalate and some carboxylic compounds. They are mixed with deet in some commercial formulations. Mixtures of different repellent substances may be effective against a wider variety of insects than single repellents.

Repellent bar

This is a recently developed inexpensive personal repellent that provides relatively long-lasting protection. It is made of materials used in soap production, such as coconut oil, and contains 20% deet and 0.5% permethrin. The bar is used by wetting it (or the skin) and producing a lather that is rubbed on exposed parts of the body (Fig. 1.40). The face can be protected by application to the neck, forehead and ears. After application a white lotion-like film remains on the skin for a short time. The residual film feels sticky and some users find it unpleasant. It is not easily removed by contact with clothes but can be removed by rinsing or rubbing. The method is considered safe but care should be taken to avoid sensitive skin areas when it is used on small children. However, it is not yet recommended by WHO for long periods of repeated daily usage, pending a full safety evaluation.

The repellent bar should be applied at sunset to provide protection during the evening. Depending on the local mosquito species and other factors, the repellent soap protects for 4 - 8 hours. Under optimal conditions, protection lasting up to 12 hours may be achieved. The amount and duration of protection have been reported to vary for different species of insects and different conditions of use (*35* - *39*).

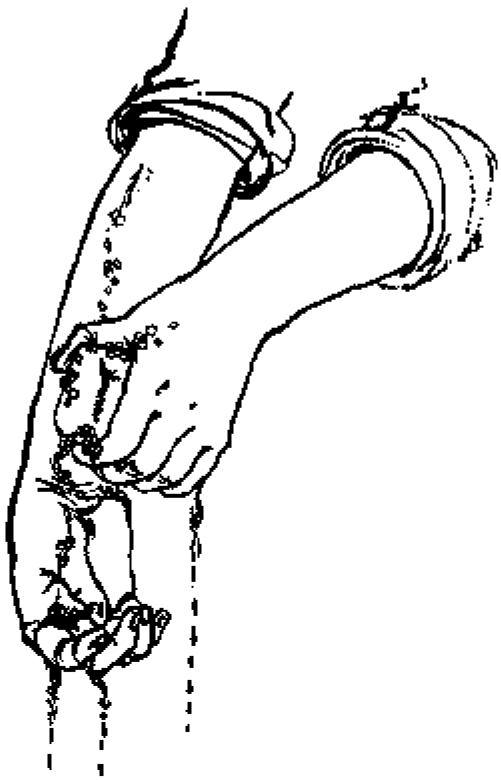


Fig. 1.40. The repellent bar.

A 40-gram bar, used daily and sparingly on arms, legs and other exposed areas, lasts approximately 20 days. Although the bar is patented, the patent holder permits local production for noncommercial purposes. The procedure and ingredients are similar to those for the production of soap.

Ingredients	*% by weight*
Crude raw coconut oil	49.86
Antioxidant, such as butylated hydroxyanisole (BHA)	0.14
Deet	20.00
Pharmaceutical-grade permethrin (25/75 *cis/trans* permethrin)	0.50
Perfume base (e.g., rose, oil of lavender)	1.00
Caustic soda solution	27.50
Natural clay	1.00

The ingredients should be obtainable from most pharmacies. Deet can be obtained from most chemical suppliers. Technical-grade permethrin is a suitable alternative to the pharmaceutical-grade compound.

Mix the permethrin with deet at room temperature and add to the coconut oil in which the antioxidant has been dissolved. Heat the resultant blend to 40 °C and add the perfume base. To this blend, add the caustic soda solution at ambient temperature, with rapid stirring. When all the caustic soda has been added, sprinkle the clay in and pour the emulsion into moulds, where the reaction continues for 12 hours. The following day, cut the blocks into 40-g bars. If the bars are wrapped in polypropylene film and placed in an airtight box the product will retain its effectiveness for more than two years. If they are packaged in a small plastic sandwich bag, or placed unwrapped in an airtight box, the shelf life is one year. If the product will be used up within a few weeks of manufacture the lower-cost packaging is sufficient.

Protective clothing

Clothing can offer protection from biting insects when it is of a thickness and texture through which insects cannot easily bite. Lighter colours generally attract fewer insects than darker colours. Boots can protect the ankles from biting insects. Thick socks in combination with long trousers offer protection when the bottoms of the trousers are tucked into the socks. Some protection is also offered by long-sleeved shirts, headnets, collars and hats. However, some insects can bite through socks or other clothes; the treatment of clothing with an insecticide or repellent can deter this.

The small biting midges, sandflies and blackflies are unable to bite through clothes, even if these are made of thin material (*40*). People active during daytime can best protect themselves by wearing thin clothing over as much of the body as possible and applying repellents to the parts of the body left exposed (*26*, *41*). Repellents are only partially effective against swarms of biting midges. Headnets or hooded wide-mesh jackets impregnated with a repellent offer good protection (*22*, *42* - *44*).

Anti-mosquito garment

A vest has been developed in the former USSR which is too thick for mosquitos to feed through and which allows the user sufficient aeration of the body. It consists of an undervest, with long sleeves made from a wide-mesh material of which the fibres are about 0.5 cm thick, covered with a long-sleeved conventional shirt (*45*).

Treated clothing

Clothing can be treated with repellents to prevent insects from landing or feeding, or with quick-acting insecticides of the pyrethroid group, such as permethrin. These latter compounds do not repel the insects but allow them to make contact with the fabric and irritate or kill them before they manage to feed. The application of repellents to clothing and other fabrics is preferable to skin application because it reduces the likelihood of allergic reactions. Limited contact with the human skin and strong adherence to fabric fibres make it possible to use higher doses of repellents and insecticides.

Synthetic pyrethroid insecticides are generally preferred to volatile repellents for treating clothing because:

- they act quickly and repel or kill biting insects;

- they are long-lasting and to some extent withstand weathering, sunlight and washing in cold water;

- they are more pleasant to use (little or no odour, colour or greasiness);

- they are safe and do not irritate human skin if applied at the correct doses (*46*);

- they do not affect plastic products;

- they are cheaper than repellents, only infrequent applications of small amounts being required.

However, if the clothing is treated with a non-repellent pyrethroid, flying insects may feed on uncovered skin, necessitating the application of a repellent to the bare skin. Because of the vapour effect, clothing freshly treated with a volatile repellent offers more protection to uncovered skin than that treated with a pyre-throid insecticide.

Impregnated socks can give effective protection against blackflies, which often bite around the ankles. Impregnated trousers and stockings provide effective protection from ticks and mites (*47*). Treated clothing is also effective against mosquitos, sandflies, biting midges, fleas and body lice (*47* - *52*). Repellents may remain effective for up to a week when applied to clothing. An extended efficacy can be obtained by sealing the impregnated fabric in a container or airtight bag when not in use to prevent evaporation of the repellent. A repellent applied to clothing normally retains its effect longer than on skin because there is:

- no loss by abrasion;
- no loss due to skin absorption;
- no removal of the active compound by sweating;
- slower evaporation because of lower temperature, except when clothing is exposed to sunlight;
- better adherence to cotton and synthetic fibres.

Clothing treated with permethrin can remain toxic to insects and ticks for several weeks or months, depending on wear and exposure to washing and rain. Treated clothing may remain effective after up to 10 rinses with cold water and soap. However, more permethrin is lost after washing in hot water and soap (*50*, *52*).

Which repellent or pyrethrold?

Any of the repellents considered safe for skin application may be used to treat clothing. Permethrin has been extensively tested and is still considered the insecticide of choice for clothing treatment (*46*). Some of the other pyrethroids, e.g. cyfluthrin, may also be suitable but most of the safe pyrethroids degrade quickly in sunlight.

How to treat clothing

Clothing can be treated with permethrin by spraying the insecticide from a pressurized can or by soaking in an aqueous emulsion. The recommended dosage for coats, jackets, long-sleeved shirts and trousers is 1.25 g/m^2 (0.125 mg/cm^2) and for short-sleeved shirts it is 0.8 g/m^2 (0.08 mg/cm^2). A pressurized spray can containing deet may be more easily available. The recommended dosage for deet is 20 g/m^2 (2 mg/cm^2), or about 70 g of active ingredient for one piece of clothing. Technical-grade deet suitable for the treatment of fabrics by dipping is available as 30% and 95% mixtures with alcohol. Treatment procedures are described on p. 85.

Treated bedsheets

People sleeping out of doors in places where the nights are cool, and for whom mosquito nets are unaffordable or impractical, could consider covering themselves at night with sheets or other fabrics treated with insecticide or repellent. This method has not yet been tested but it can be expected to be as safe and effective as use of treated clothing. For complete coverage of the body in hot climates it would be possible to use thin, open-weave fabrics that allow unobstructed breathing.

Insect-repellent wide-mesh netting jackets

Special jackets made of wide-mesh netting, with a hood to protect the head, may provide sufficient protection from biting insects when impregnated with deet or other repellents (Fig. 1.41; *43*, *53* - *56*). They are especially suitable for people on brief visits to areas infested with high densities of mosquitos and other biting insects, as in northern Siberia, Scandinavia and Alaska. Open-mesh material offers the advantages that it can be used in combination with normal clothing or with no clothing beneath and that it is relatively cool.

A disadvantage is that the netting easily gets entangled in dense vegetation; it is most practical in areas with little vegetation. The jackets can be made of strong wide-mesh cotton or a mixture of polyester/cotton or nylon. Mesh jackets sold in Canada and the USA are made of polyester netting containing strands of cotton. Cotton is required to absorb the desired treatment level of 0.25 g of deet per gram of netting (or 10 - 15 g of deet per m^2). The jackets should be stored in an airtight plastic bag when not in use.

Insect-repellent headnets

Wide-mesh netting similar to that used in the jackets described above can be employed to protect the head and neck (Fig. 1.42; *57*, *58*). It is preferably used in combination with a hat or other head covering. The netting allows good visibility and ventilation.

Insect-repellent bands and anklets

Many species of bloodsucking insects bite predominantly around the ankles and wrists. Strips of cotton fitted around the extremities and impregnated with a repellent reduce biting substantially (Fig. 1.43; *18*, *59*). The cotton strips are about 10 cm wide and 35 cm long and can be provided with buttons and buttonholes or can be elasticized (like sweat bands) so that they remain in place.

Fig. 1.41. Wide-mesh netting jackets impregnated with repellent provide protection from mosquitos and other biting insects.

The bands are used with a repellent rather than an insecticide because repellent vapour action protects nearby uncovered areas of the body. When not in use, the anklets should be stored in an airtight plastic bag or tin to reduce evaporation of the repellent. The recommended dosage of deet concentrate (95%) for one band is 4 ml, or the band may be saturated in a 30% deet/alcohol mixture. If used for about 2 hours each evening, deet-impregnated bands remain effective for at least 50 days.

Insect-repellent detachable patches of fabric

The treatment of clothing can be avoided by using detachable patches of fabric impregnated with repellent. The patches can be attached by, for example, press buttons or Velcro strips. In one study (*59*), four 15-cm × 15-cm pieces on the front of a shirt and one on the back were found to reduce mosquito bites considerably over a period of more than two months when used twice a week. The patches can be treated by soaking in a 10% solution of deet or DEPA and should be stored in airtight plastic bags when not in use. The advantages of the treated patches are that they do not come into direct contact with the skin, they can be removed when clothing has to be washed, and they provide more economical and simpler treatment.

Fig. 1.42. Headnets impregnated with repellent can be used to protect the head and neck from mosquitos and other biting insects.

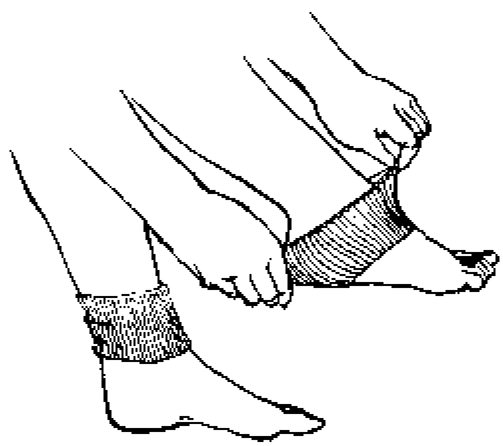


Fig. 1.43. Anklets impregnated with repellent stop insects from biting the ankles, feet and lower legs.

Insecticide vaporizers

Unlike repellents, only a few insecticides, such as dichlorvos, have a spatial effect at normal room temperature. However, some insecticides kill or repel insects at a distance through an airborne effect when vaporized with a heating device. Insecticides can also be released into the air as aerosols, for example when sprayed from pressurized spray cans.

Dispensers releasing insecticide into the air help to protect people nearby. Traditionally, plants or wood containing repellent or insecticidal substances have been burned (*23*, *60*). More modern devices include mosquito coils, vaporizing mats, dichlorvos dispensers and aerosol spray cans; these are relatively inexpensive and may protect several people at a time. However, their use is confined to houses and other places with limited ventilation. They may be effective in dense vegetation where the repellent is not too diluted by air movements. The compounds used are mostly quick-acting knockdown insecticides with both a killing and a repellent effect, for instance the allethrins, a group of pyrethroid insecticides. The allethrins are considered to be safe to humans if used properly.

Insecticide vaporizers protect against mosquitos and biting flies by:

- preventing them from entering a room (deterrent effect);

- irritating and disturbing them after contact (excito-repellent effect) and preventing them from biting;

- paralysing or killing them (insecticidal effect).

Mosquito coils

Coils (Fig. 1.44) are among the most popular and widely used insecticide vaporizers because they are easy to use, effective (*61 - 66*) and inexpensive. Once lit, coils smoulder at a steady rate for 6 - 8 hours, steadily releasing insecticide into the air.

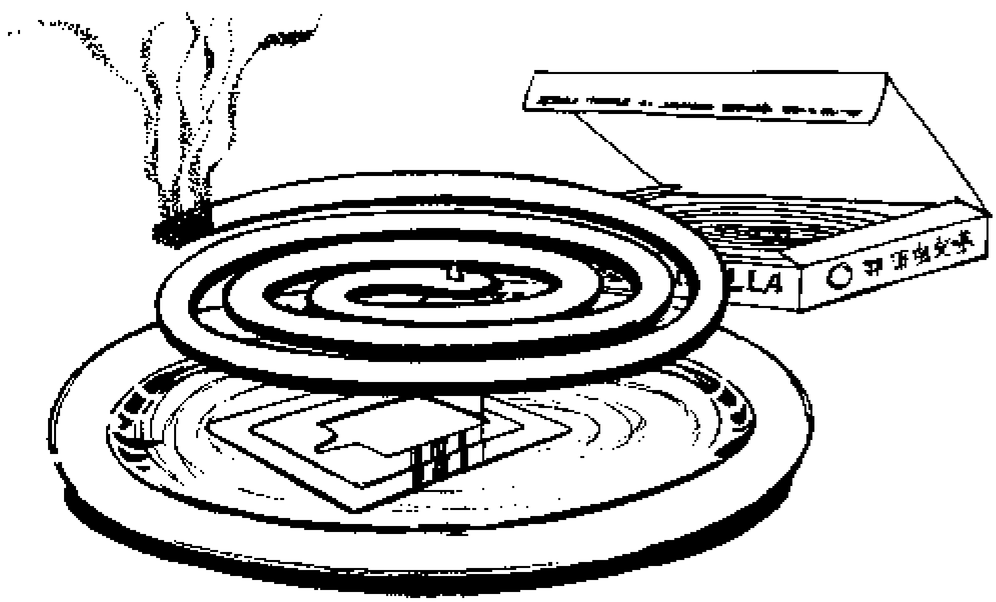


Fig. 1.44. Mosquito coils are among the cheapest and most commonly used insecticide vaporizers.

Originally, mosquito coils consisted of a mixture of pyrethrum powder (see box), a combustible filling material, such as sawdust, and a binder, such as starch. Some of the synthetic pyrethroids, especially knockdown agents like the allethrins, are now commonly used in coils. They are more effective and more easily obtainable than pyrethrum (*61*). DDT is an ingredient of some brands of coil in China but is ineffective when used in this way (*61*). To make the smoke more acceptable the coil sometimes incorporates a fragrance. The shelf-life of coils is at least three years if they are packed in paper or plastic and stored in boxes, protected from light and moisture.

Pyrethrum

The pyrethrum plant (*Chrysanthemum cinerariaefolium*) contains several active substances (pyrethrins) that are toxic to insects. The active material can be extracted with a solvent from the dried flowers (Fig. 1.45) and stems and has commonly been used in sprays for quick knockdown of flying insects. Dried pyrethrum flowers, ground to a powder, or the extract obtained from them, are used to produce anti-mosquito sticks and coils. However, because of the uncertainty of supplies and the introduction of more effective synthetic pyre-throids, the use of pyrethrum has declined.

Fig. 1.45. The pyrethrum flower (© WHO).

How to use

The coil is placed on a suitable stand and the free end is lit. A metal stand is normally provided in a box of coils. The stand ensures that the coil does not touch or rest on a surface, which might cause it to go out or to set fire to nearby flammable objects. When used indoors, coils mounted on stands should be placed on a fireproof base, such as a saucer or plate and as low as possible in the immediate vicinity of the people to be protected.

The coils should be lit just before mosquitos become active. One coil is sufficient for a normal bedroom (35 m^3). In confined areas such as a closed tent or a small closed room, the smoke may cause irritation to the eyes and lungs. For larger spaces, several coils should be placed at different points. If rooms are ventilated or if the coils are used outdoors it is important that they are upwind of the people to be protected.

If lit in the evening, a coil can provide protection until early morning. However, a strong draught in a room with an open door or windows, or windy conditions outdoors, may significantly speed up the rate of burning while dispersing the insecticide and diluting its effect. For better protection a coil should be used during the early evening hours indoors (or a repellent should be applied to exposed skin or clothing outdoors) and a mosquito net should be used indoors during the remaining part of the night.

Coil holders

The efficacy, convenience and safety of coils can be improved by placing them in special containers or holders. Holders may prolong the burning time by up to 20%. Holders also protect the burning coil from wind and rain, and prevent flammable objects from making contact with it. Various models of coil holder are widely available in Asia (Fig. 1.46). They can also be easily made from used cans with the metal stand soldered to the bottom. The can itself is perforated with small holes in the side and top.

Portable coil holder

People working in forested areas where there is not much wind (woodcutters, rubber-tappers, plantation workers, gold- miners) can obtain some protection from biting mosquitos and phlebotomine sandflies by attaching one or two smouldering coils in special holders to their belts (Fig. 1.47). Each coil is kept in place between two pieces of metal or non-flammable fibre glass gauze. The advantages of coil holders over skin repellents are that they are cheaper, do not elicit any skin reactions when used frequently, and are not washed off by perspiration.

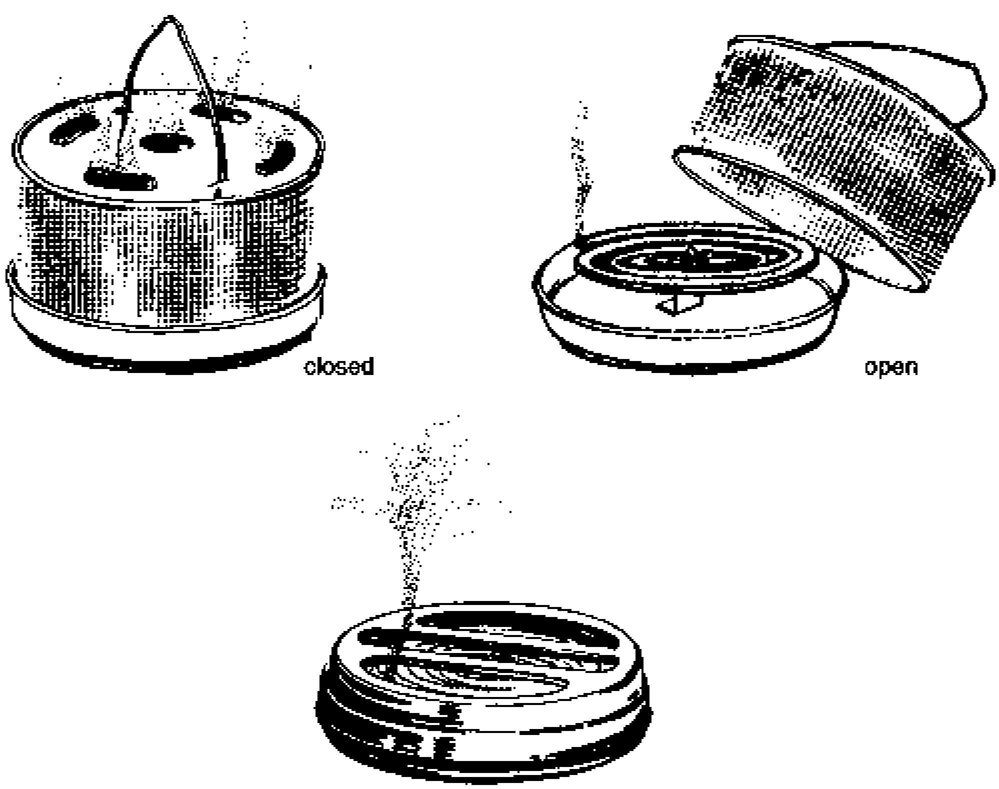


Fig. 1.46. Commercially available coil holders. The holders are commonly used in Asia, especially in crowded rooms. They improve the performance, convenience and safety of smoul-dering mosquito coils.

How to make coils

Coils can be made cheaply from an insecticide and a flammable base material (*67*).

Ingredients	***% by weight***
1.3% pyrethrum powder	20 - 40
Water-soluble glue (starch gel)	25 - 30
Filler (coconut shell flour, sawdust, jute)	30 - 40
Fungicide (benzoic acid, sodium dehydroacetate)	0.2 - 0.5

More effective alternative insecticides are (+)-allethrin (0.2 - 0.3%) and (+)-*trans*-allethrin (0.10 - 0.15%). If one of these is used the quantity of filler is increased to 60 - 80%. To regulate burning, commercially produced coils often contain potassium nitrate. The sawdust particles have to be of the correct dimensions, otherwise the coil does not burn well. This has to be determined by trial and error. Mix the ingredients thoroughly and add an equal weight of water to produce a uniform and homogeneous paste. Compress the mix in a mould of the desired shape and place on a rack to dry. A suitable mould can be carved out of a piece of wood. If the device is meant to burn for many hours a coil shape is the most convenient. For shorter periods (3 - 4 hours) it is possible to give it the shape of a long thin stick.

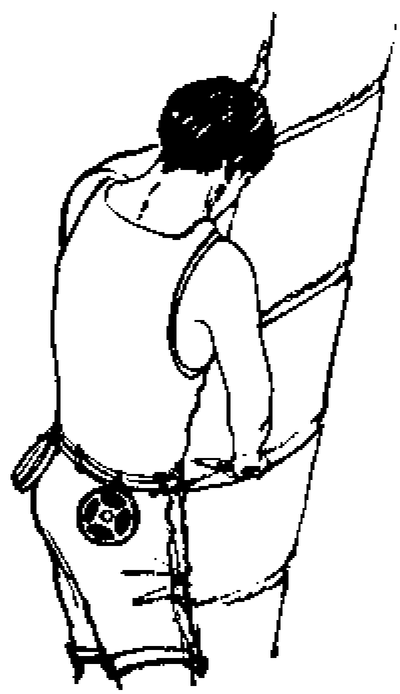


Fig. 1.47. A rubber-tapper with a special portable coil holder attached to his belt.

Repellent ropes

A cheaper alternative to mosquito coils has been developed in India (*68*): ropes soaked in a solution of a suitable insecticide, when burnt, produce a smoke that kills and repels mosquitos and biting flies. The recommended material, widely available in

India, consists of jute fibres, is about 0.9 cm in diameter and weighs about 28 g/m. Esbiothrin was used in India, but other insecticides used in mosquito coils would also be suitable. A 1.2-m impregnated rope will burn for 10 - 12 hours if hung indoors from a ceiling. The ropes are preferably burned inside cylinders of wire mesh to prevent them from making contact with flammable materials.

How to impregnate ropes:

If esbiothrin is used for impregnation the recommended dosage is 1 ml/kg: 1 ml of technical-grade esbiothrin is dissolved in 1.15 litres of kerosene, and a 1-kg jute rope is dipped into the solution until saturated. The rope is dried in the shade and stored in a box or bag until required.

Vaporizing mats

Where electricity is available, small electric heating plates can be used to vaporize volatile insecticides from mats (Fig. 1.48). This popular method has the advantage over coils that no visible smoke is produced. The mat is often a porous paper pad measuring 35 × 22 × 2 mm, impregnated with an insecticide. The mats are packed in foil to prevent evaporation of the insecticide before use. The insecticides are usually allethrin pyrethroids, e.g. bioallethrin, esbiothrin and esbiol, which are considered to be safe to humans but have a rapid killing and repellent effect on mosquitos and biting flies (*62*, *69*).

The mats contain an indicator dye that changes colour from blue to white in about the same time that it takes for the insecticide to evaporate. If used in a room of about 35 m^3, a mat containing, for example, 40 mg of (+)-allethrin or 20 mg of (+)-*trans*-allethrin will last for 8 - 10 hours. However, towards the end of the period less insecticide will be released. In larger rooms more than one mat, or mats containing more insecticide, should be used.

Several types of electrical heater are sold with the mats. All have a flat pad-like resistance unit (5 to 6 watt) mounted in a ventilated plastic case. Some models are directly plugged into a power point. The heater normally produces a temperature of 160 °C between the mat and the heater and 125 °C on the upper surface of the mat. A mat temperature of about 145 °C is needed for vaporizing the insecticide. Some heaters on the market do not achieve this temperature and therefore do not vaporize the insecticide sufficiently. A heater takes about 30 minutes to reach its operating temperature.

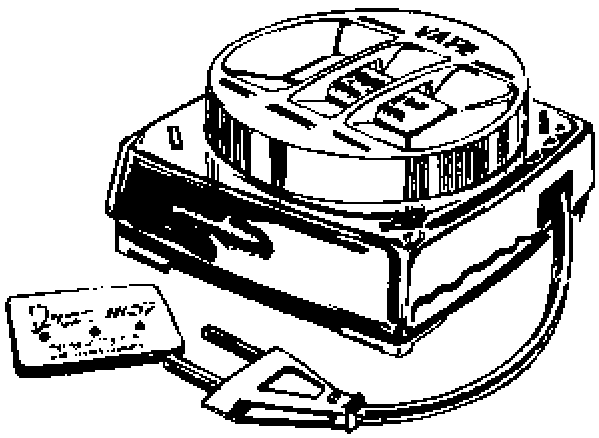


Fig. 1.48. An electrical heater unit for vaporizing insecticide from mats.

Electric liquid vaporizer

This device is a technological improvement on vaporizing mats. The insecticide is evaporated by an electric heater through a porous wick from a reservoir bottle containing the liquid (Fig. 1.49). The liquid insecticide lasts for up to 45 periods of 8 - 10 hours. Many models are controlled by a switch and have a pilot lamp.

This method is more convenient and more effective than the mat heater because the amount of insecticide released remains constant over time, but for the moment it is more expensive.

Dichlorvos dispenser

Dichlorvos is a volatile liquid whose vapour is highly toxic to flying insects. Liquid dichlorvos impregnated into a special absorbent material, such as polyurethane, slowly evaporates without the need for a heating device. A dispenser usually consists of a piece of polyvinyl chloride plastic or a resin saturated with liquid dichlorvos, mounted in an open plastic support (Fig. 1.50). Some dispensers are strips measuring 5 × 25 cm, while others have the shape of a small box. They are sealed in an airtight package to avoid premature vaporization of the insecticide.

The dispenser in its plastic support is placed at a height of 1 - 2 m above the floor or is suspended from the ceiling. Most models contain sufficient dichlorvos to treat a room of 15 - 30 m^3 for 1 - 2 months. A strong draught will shorten the period of effectiveness. The advantages of this method are the long period of effectiveness and the lack of a need for electricity, making it especially suitable for use in rural houses, tents or caravans.

The continuous exposure of young children and sick or elderly people to dichlorvos in poorly ventilated rooms should be avoided. Some reports suggest that continuous exposure to dichlorvos may have caused health problems in a few people.

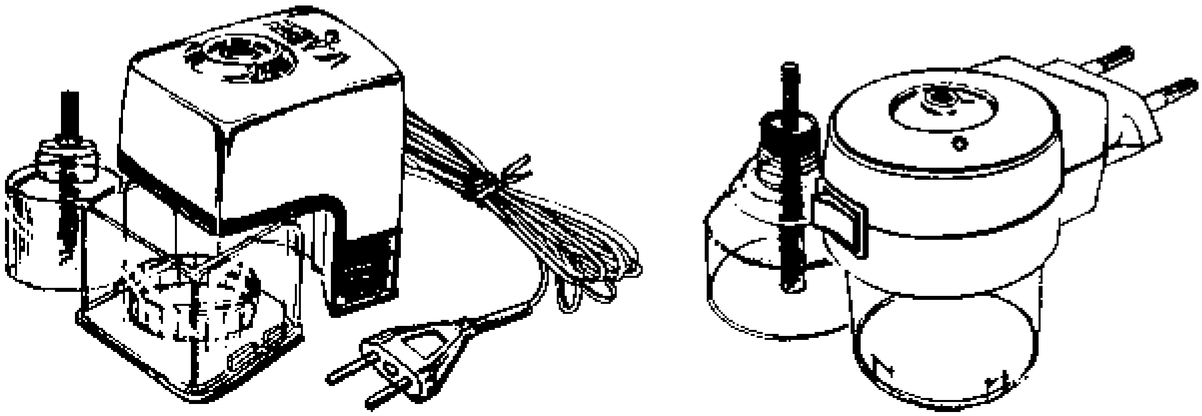


Fig. 1.49. Two models of electric liquid vaporizer.

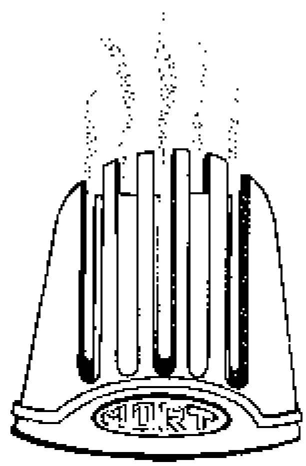


Fig. 1.50. A dichlorvos dispenser releases a volatile insecticide continuously without heating for 1 - 3 months.

Pressurized spray cans

Pressurized cans provide a convenient method of spraying insecticidal aerosols in rooms, on mosquito nets, vehicles and so on, to obtain rapid knock-down of mosquitos and other flying insects. The spray cans contain a concentrate of the insecticide in an organic solvent or water together with a liquefied or compressed gas propellant. Pyrethrum used to be the common ingredient in many different brands of aerosol sprays. Today, however, the synthetic pyrethroids and to a lesser extent the carbamates (propoxur and bendiocarb) and organophosphorus compounds (dichlorvos) are the main active ingredients. The spray may contain a “knock-down” agent to give a rapid effect, a slow-acting agent that actually kills the insect, and a synergist - usually piperonyl butoxide - to increase the activity of the ingredients. In view of worldwide concern about the use of chlorofluoro-carbons, which may affect the ozone layer of the atmosphere, most brands now contain other propellants.

The spray can is operated by briefly pressing a valve incorporating a nozzle on top of the container. The spray can be directed against flying or crawling insects or sprayed into a room (Fig. 1.51). Rooms should then be kept closed for about 15 minutes in order to kill as many insects as possible. The hiding and breeding places of cockroaches, fleas, lice and bedbugs can be sprayed directly from a distance of about 20 cm.

Space sprays have a very short residual effect: once the aerosol has settled out of the atmosphere insects can again enter the area with impunity. Furthermore, the active ingredients (commonly (+)-allethrin or (+)-*trans*-allethrin) are rapidly degraded by light. An advantage of short-lasting insecticides is that they do not leave any toxic residues on beds, furniture or other surfaces. This method works best in screened spaces and can be repeated daily or several times a day.

The spray can is under pressure and should not be exposed to direct sunshine or temperatures over 50 °C. Most sprays contain the flammable substances propane or butane and should not be directed at fires or smouldering objects, e.g. cigarettes.

Fig. 1.51. Aerosol sprays containing rapidly acting insecticides are used for immediate killing of flying or crawling insects.

Water-based aerosol spray

Water-based aerosol sprays have recently been developed and are claimed to offer the following advantages over oil-based aerosols: they leave no oil residues or stains on surfaces, do not produce an unpleasant smell or an irritant effect, and are not flammable. However, the droplets of oil-based aerosols are usually finer and more effective. The cans must be shaken well before use.

Spray gun

Before the invention of the pressurized disposable spray can, a hand-compressed spray pump was commonly used. This spray pump has a reservoir which can be filled with a solution of pyrethrum or other insecticide (Fig. 1.52). It is cheaper to use a spray gun than to buy pressurized spray cans. However, the droplets in the aerosol from a spray can are finer, stay in the air longer and are usually more effective. Spray guns are nowadays used mainly against crawling insects.

Spray guns and the liquids to fill them are commercially available in some countries. The liquids can be based on equal parts of kerosene and alcohol, to which are added a small quantity of one or two quick-acting insecticides and a perfume.

An example of a standard insecticide mixture is:

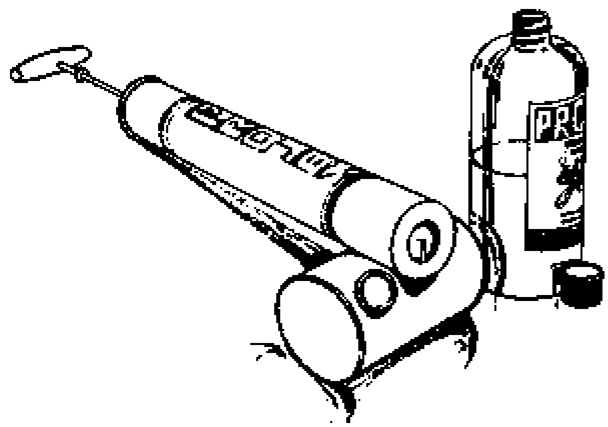


Fig. 1.52. Spray guns are pumped by hand in order to deliver aerosols.

Bioallethrin	0.1%
Permethrin	0.5%
White spirit (or pure alcohol)	49.7%
Kerosene	49.7%

Propoxur and dichlorvos are among the many other insecticide mixtures that can be used.

Electronic buzzers

Battery-operated electronic devices that produce a high-pitched buzz have been widely sold as mosquito repellents. Some manufacturers have claimed that they simulate the sound of a male mosquito and that this sound is repellent to mated females. Others claimed that the buzzers simulate the sound of the dragonfly, thus inducing mosquitos to fly away. However, several independent scientific investigations in different countries have convincingly demonstrated that these electronic gadgets provide no protection from biting mosquitos (*70*, *71*). An apparently positive test by producers was faulty in design. In the United Kingdom some companies have been fined for making unsubstantiated claims in their advertisements for buzzers.

Protection measures in hammocks

Hammocks are used in many parts of the world for sleeping and resting. They are often used in jungle areas and offer the following advantages over other sleeping places:

- they are not easily accessible to crawling insects, scorpions, snakes and other small animals;
- they are well ventilated and suitable for use in hot climates;
- they provide dry sleeping places and are not in contact with damp soil;
- they are light and easily folded and are therefore easy to transport.

However, they do not protect the user from flying insects. Mosquitos often settle and feed where the body touches the lower part of the hammock (Fig. 1.53). At night the use of hammock mosquito nets (see p. 79) can offer protection but during daytime the use of nets is often considered inconvenient for various reasons, among them poor visibility and reduced ventilation.

Suggestions for protection in the absence of a mosquito net

• Application of a volatile repellent such as deet to the lower part of the hammock at a dose of about 20 g/m^2. The repellent persists for only a few days and some mosquitos may try to feed from above.

• Placing a burning mosquito coil close to the hammock. If used in a coil holder it is safe to place the smouldering coil under the hammock.

• A method that provides longer-lasting protection is the impregnation of the whole hammock or the lower part of it, using a sponge, with a quick-acting pyrethroid insecticide. Mosquitos making contact with the treated part of the hammock are killed or incapacitated. Because of the thickness of the hammock material this method requires a relatively high dose of insecticide (1.5 g of permethrin or more per m^2).

• A more economical method, requiring far less insecticide and probably equally effective, is that of protecting the lower surface of the hammock with an impregnated piece of netting or cloth (Fig. 1.54). This material can be loosely attached to the hammock with a few pins or with stitches. It should be attached close to the hammock so that mosquitos are more likely to settle on it and be killed. However, the netting should not touch the hammock except where it is pinned or stitched on, because this would enable some mosquitos to feed before being killed. The advantages of using removable material are that it is easily impregnated, can be removed when the hammock is washed, and can be stored in an airtight box when not in use.

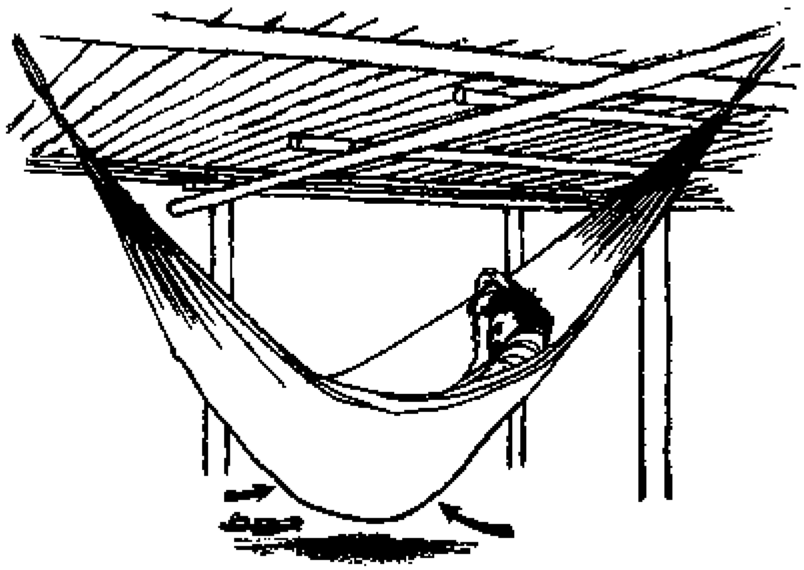


Fig. 1.53. Mosquitos often attack the occupant of a hammock from below, where the body presses against the lower part of the hammock.

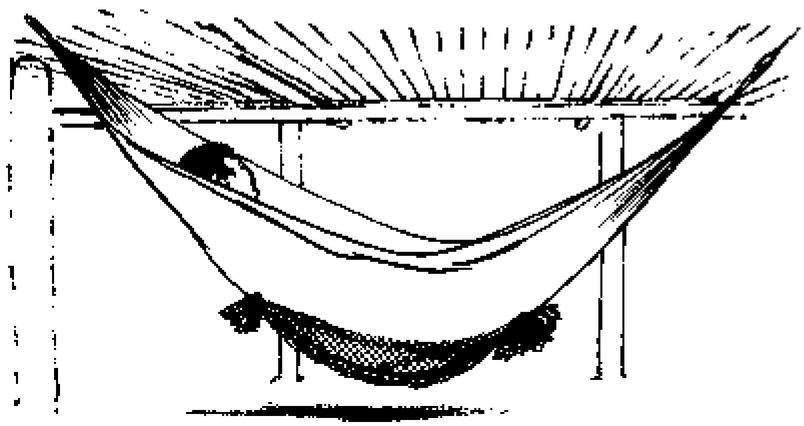


Fig. 1.54. A piece of cloth or netting impregnated with an insecticide or repellent and loosely attached to the lower part of a hammock can provide partial protection from biting mosquitos.

Mosquito nets

Mosquito nets (Fig. 1.55) have been in use since very early times to protect people against bloodsucking insects at night; they also help to protect against other creatures, such as spiders, cockroaches, beetles, lizards, snakes and rats. When made of thicker opaque sheeting they also protect against cold and dust, and provide privacy.

Mosquito nets normally have a mesh size of 1.2 - 1.5 mm, which is sufficiently small to prevent mosquitos from entering. Very small insects, however, such as phlebotomine sandflies and biting midges may enter. Only opaque sheeting, very fine-mesh jersey netting (mesh size less than 0.2 mm), and impregnated netting (see p. 82) offer protection against these insects. In hot climates, poor ventilation through fine-mesh netting is a serious disadvantage. The wider the mesh size the better the ventilation, but if the mesh is more than 2 mm most mosquitos can enter.

Netting materials

Traditional netting materials are linen, raffia (palm fibre) and hemp. Nets are now made of cotton or synthetic fibres (nylon, polyester or polyethylene). The quality of a mosquito net depends on the thickness and strength of the threads and on the production process. The threads in a mosquito net can be woven or knitted (Fig. 1.56). A disadvantage of woven nets is that the threads can slide over each other, thus creating enlarged holes through which mosquitos can pass. However, in woven nets made of stiff, polyethylene fibres this does not seem to be a problem.

Synthetic nets usually cost less and are less likely to rot than cotton nets. Inexpensive nets of cotton, nylon or polyester often contain starch, which gives a less flimsy, more attractive appearance. The starch dissolves when the nets are washed.

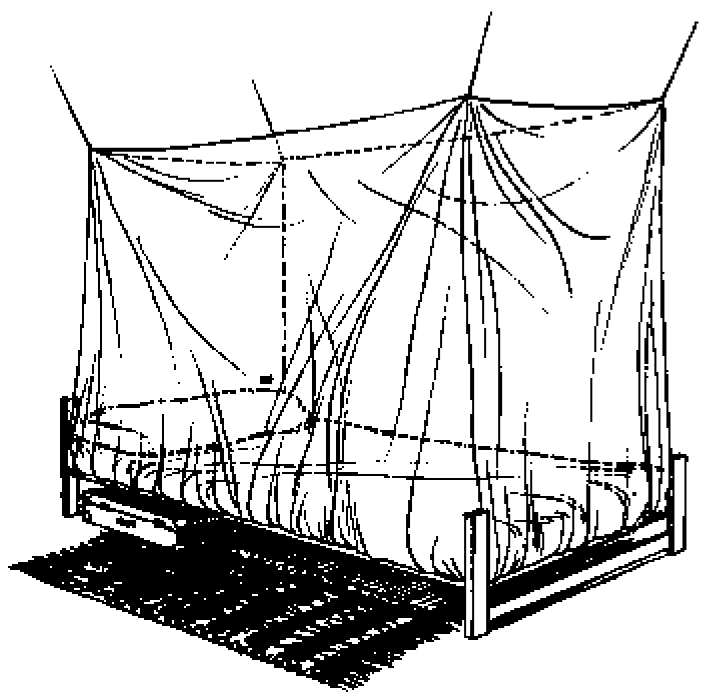


Fig. 1.55. A rectangular mosquito net.

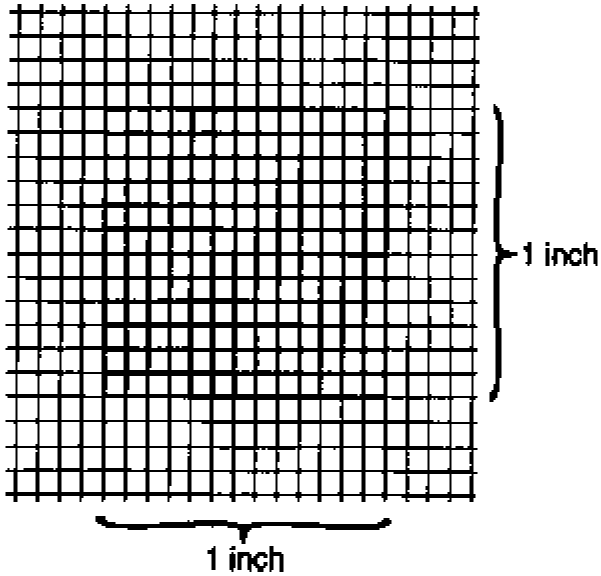


Fig. 1.56.(a) The mesh of a mosquito net is traditionally indicated by the number of holes to the square inch. The netting shown here has a mesh of 156 (12 × 13) (actual size).

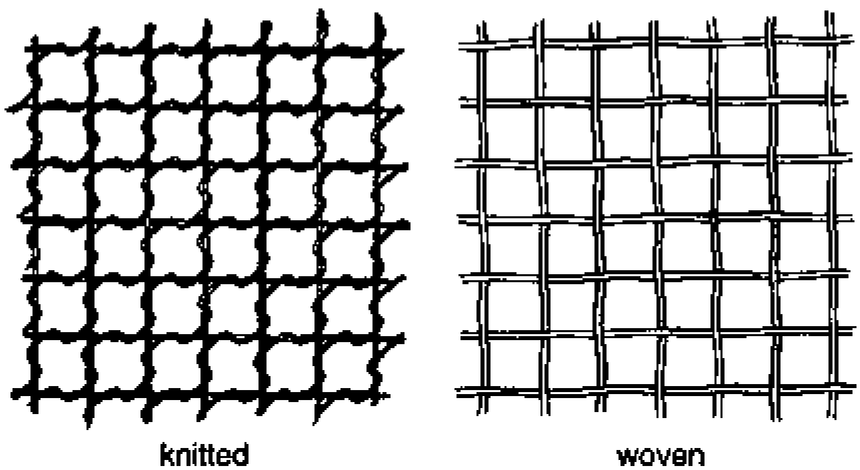


Fig. 1.56.(b) Close-ups of knitted and woven netting material.

Some terms for characteristics of netting material

Mesh: the number of holes per square inch. For example, mesh 156 has 12 × 13 holes per square inch (see Fig. 1.56).

Mesh size: the size of the openings in a net. It is determined by the number of holes per square inch (the mesh) and the thickness of the threads with which the netting is made. The mesh size recommended for most tropical countries is between 1.2 and 1.5 mm.

Denier: an indication of the weight (and therefore the strength) of the thread. It is defined as the weight in grams of 9000 metres of a single thread. Commonly used mosquito net threads have a denier between 40 and 100 but denier 40 is easily torn and 70 or more is recommended.

Strength: an indication of the pulling strength of a thread, expressed in grams per denier. If 1 metre of 40 denier thread breaks with a load of 160 g, the strength is 4 g per denier.

Monofilament/multifilament fibre: the thread of a mosquito net consists of one or more fibres. A nylon or polyester fibre is multifilament (consisting of many filaments), while polyethylene fibres are monofilament.

Sheeting border: nets are often provided with a strong border of cotton sheeting or synthetic jersey. This protects the net from wear due to daily tucking in of the net under the mattress. If the border is wide enough (30 cm) the extra material will also reduce bites from insects that may make contact with the lower part of the net whilst the occupant is asleep.

Ceiling: fine-meshed jersey or other opaque material is often used as a ceiling for the net to prevent dust from falling through.

Colour: white material is most commonly preferred but other colours are available. In a white net it is easier to see any mosquitos that have entered. A darker colour may be preferable because nets are less likely to appear soiled.

Mosquito net models

Mosquito nets are produced in different sizes and shapes. A net should cover the sleepers completely and should be sufficiently spacious for them to avoid contact with the fabric. Sufficient length is needed so that the net can be tucked in under the mattress or sleeping mat. Various models have been developed for specific circumstances. They differ in convenience for daily use, and prices vary widely. The method of suspension is an important consideration.

Rectangular net

This is the most popular and practical model, normally used over a bed or sleeping mat. It is suspended from four or more loops along the upper edges. This model can be provided with an overlapping entrance flap of about 60 cm on one of the long sides to facilitate entering or leaving without pulling out the part of the net tucked in under the mattress (Fig. 1.57). Care should be taken to ensure that the overlap is properly closed to keep mosquitos out.

Dimensions vary: most nets have a height of about 150 cm and a length of 180 - 190 cm. A single-size net has a width of 70 - 80 cm, contains about 9 m^2 of netting material, and is used to cover one person on a single bed or sleeping mat. Double nets with a width of 100 - 110cm (10 - 11 m^2 of netting) and family-size or large double nets with a width of 130 - 140 cm (12 - 13 m^2 of netting) are used for larger beds. Extra-large nets with a width of 180 - 190cm (14 - 15 m^2 of netting) are used for very large beds and where several family members sleep together on a sleeping mat in one room. The optimal size depends on sleeping habits and available space.

Very large nets are sometimes used by groups of people (e.g. in Mauritania) who spend the early evening hours together. These nets are used in shelters that provide shade during daytime but do not have walls.

Special supports for rectangular bednets

Indoor supports Where it is customary to rearrange and use beds for seating during daytime, nets should be supported using detachable poles or mosquito net supports attached to the ceiling or wall (Figs. 1.58 and 1.59).

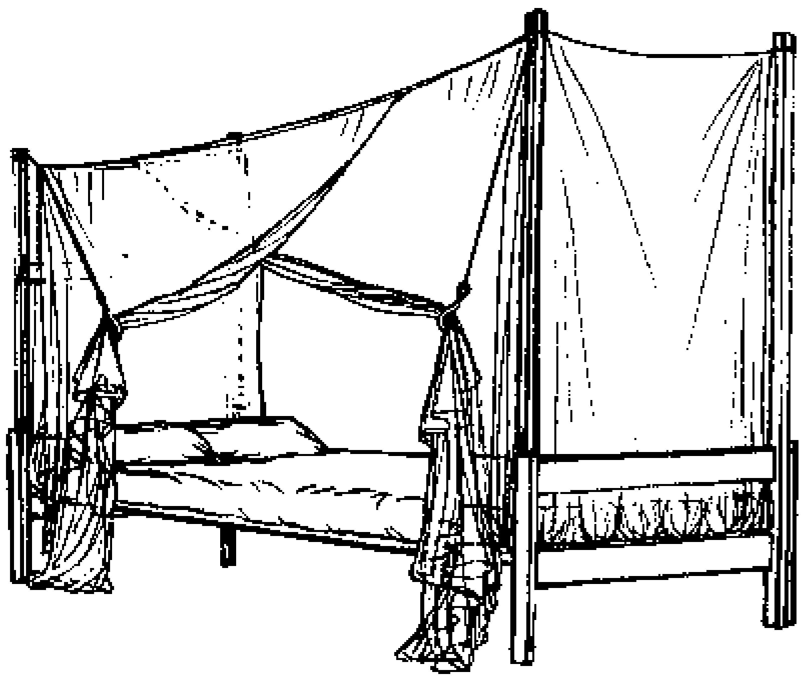
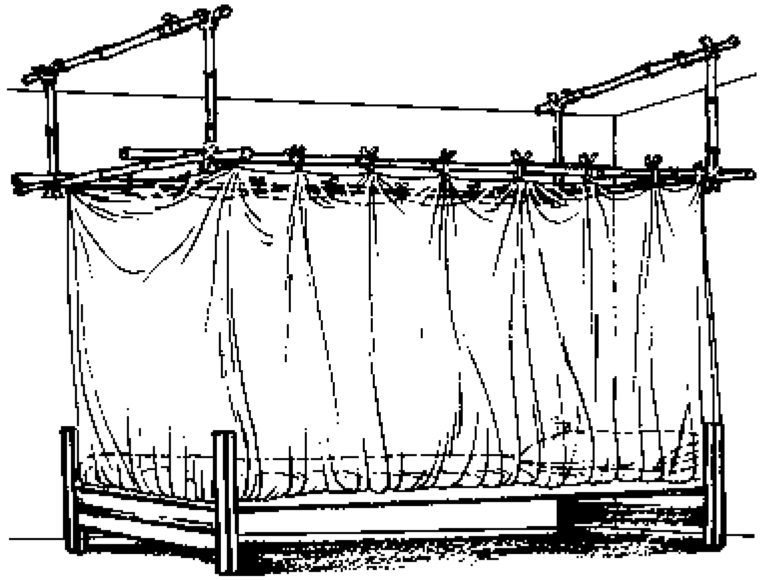
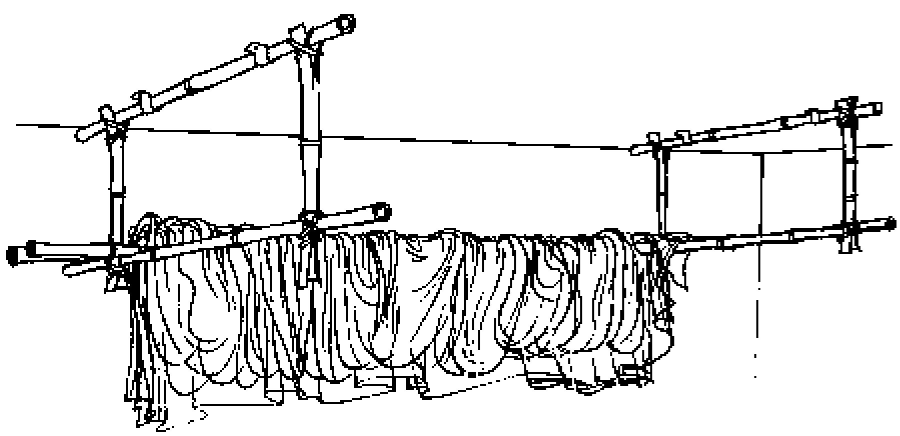


Fig. 1.57. A rectangular net with an overlapping entrance flap.



at night



during daytime

Fig. 1.58. A support system for a rectangular net which enables quick and easy overhead storage during the day. The components can be made of bamboo, wood or plastic.

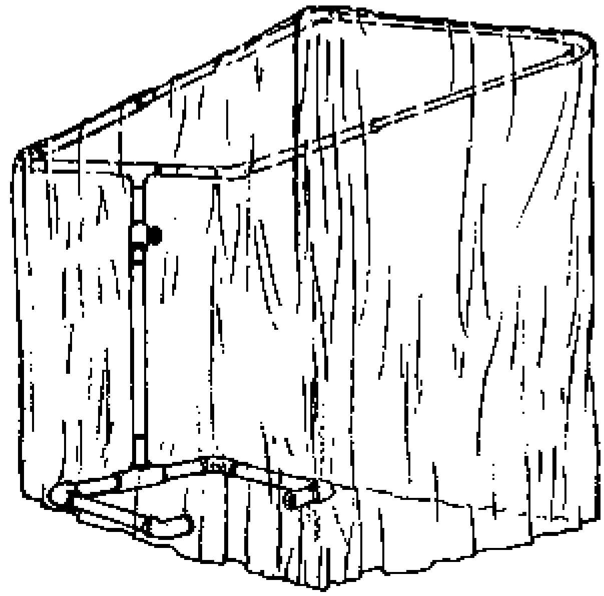


Fig. 1.59. A support system for a rectangular net which can be used indoors or outdoors (adapted from *72*).

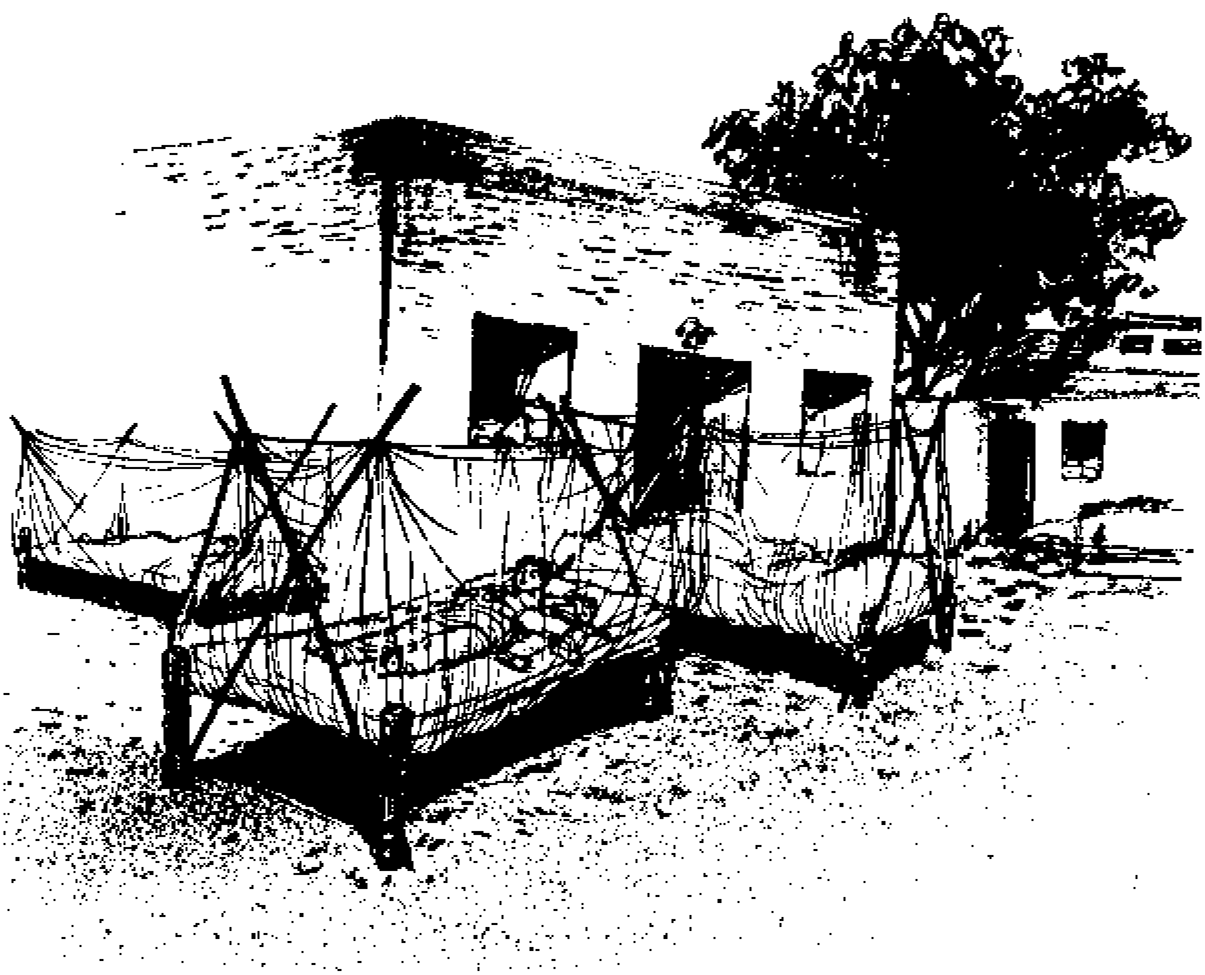


Fig. 1.60. Flexible wooden poles can be placed in a crossed position at the ends of the

bed with the lower ends tied or attached to the legs of the bed. The poles and net are easily removed during daytime.

Outdoor supports Where people habitually sleep outdoors during the hot season nets are best supported by a frame that can be easily detached from the bed (Fig. 1.60) (*72*).

Circular net

Circular, or conical, nets are often preferred because they can be hung from a single support (Fig. 1.61). The top is suspended by a loop attached to a sleeved hoop of rattan or plastic. The nets are mostly available in double size. Compared with the rectangular net, more care has to be taken to avoid contact between the body and the net, which would allow mosquitos to feed.

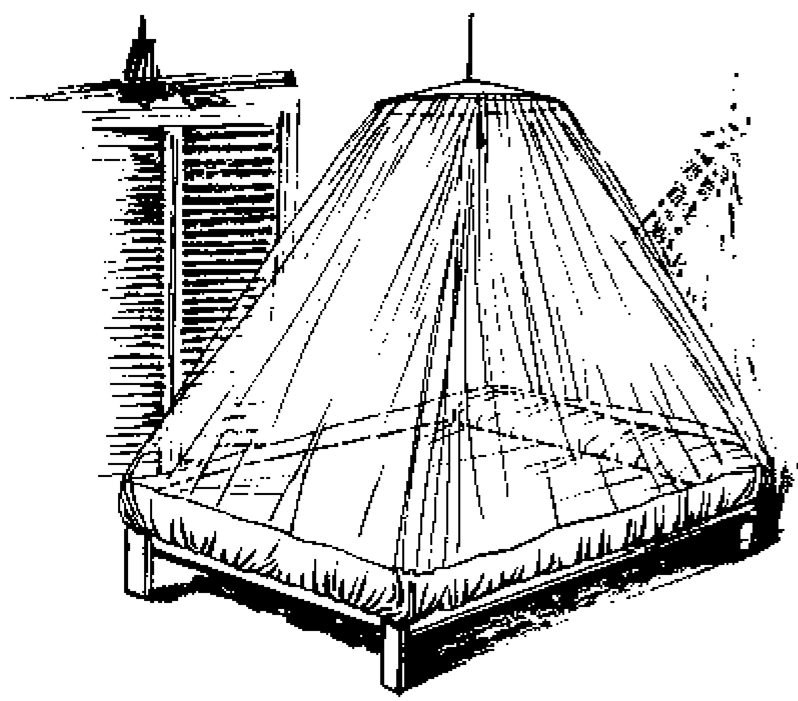


Fig. 1.61. A circular net suspended from a single support.

Wedge-shaped net

Wedge-shaped nets are available only in single size. They are much cheaper than rectangular bednets because only about half the netting material is needed. The head end is suspended by a loop attached to a sleeved wooden bar. It can be hung from any suitable fixing point above the head of the bed or sleeping place. The foot end, which is made of thick material so that mosquitos cannot feed on the feet, must be firmly tucked under the mattress or otherwise secured (Fig. 1.62). Because of its small volume when folded and because it can be suspended from a single point, the wedge-shaped net is convenient for travellers and campers.

Self-supporting nets

These nets are available in small sizes. Usually marketed for the protection of food from flies, they are also used to protect babies and infants (Fig. 1.63). Because the nets are self-supporting they are easy to set up indoors and outdoors.

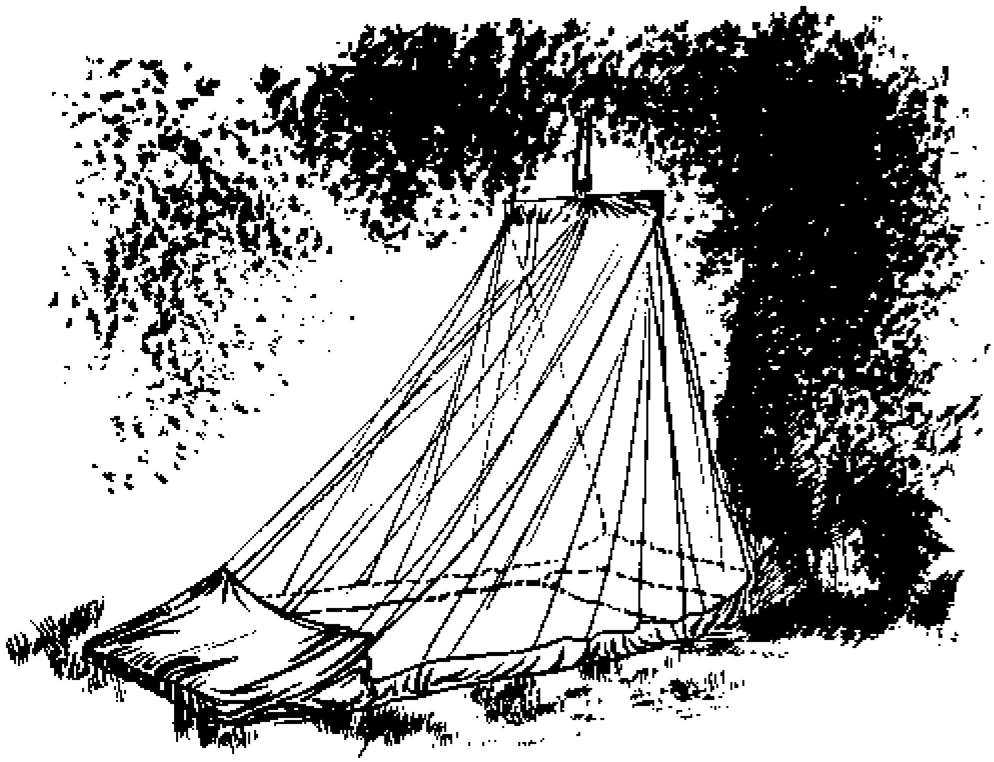


Fig. 1.62. A wedge-shaped net.

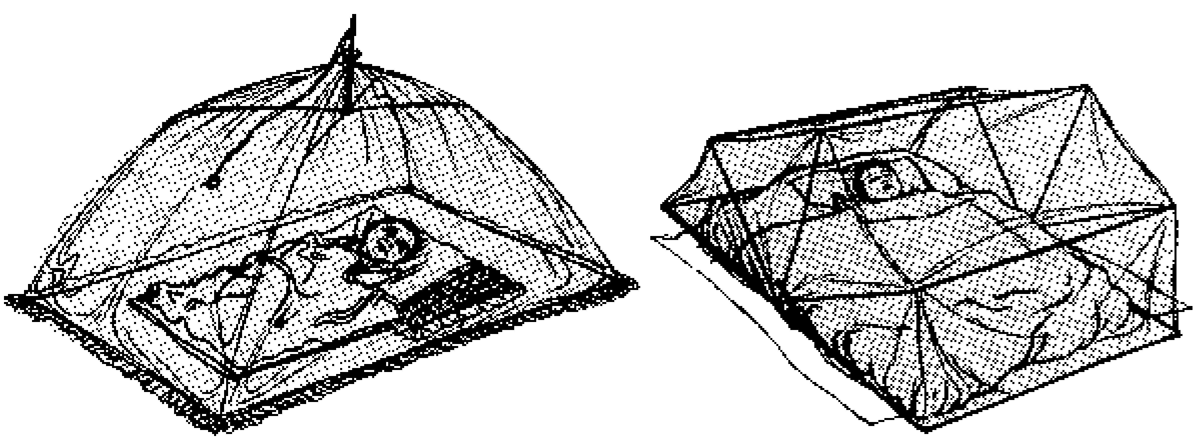


Fig. 1.63. Two self-supporting nets used to protect babies and infants. The collapsible "umbrella" net (left) is commercially available. The other model (right) is also collapsible and consists of U-shaped pieces of wire; it is easy to make.

Camp bed with protective cover

A collapsible camp bed with a self-supporting cover has been developed for use by workers in rainforest areas, for instance gold-miners in the Amazon region. The cover is a detachable part of the bed and consists of waterproof (polypropylene) sheeting with built-in ventilation openings of mosquito gauze and a door of mosquito netting closed with a zipper (Fig. 1.64). It is more comfortable than a hammock with a mosquito net, but it is also more expensive and more bulky.

Mosquito nets for hammocks

Special mosquito nets are available for hammocks; these are similar to rectangular bednets but have sleeves for the hammock ropes at each end. In some areas these nets are made from opaque cotton cloth which offers privacy, provides additional protection from the cold and is more sturdy. To prevent mosquitos from entering, the nets can be left hanging down to touch the ground.

If the ground surface is dirty or if there is a need to prevent small animals from climbing up the net, it can be closed by pulling up one side under the hammock with strings and tucking the other side into it. The sleeves are tightly closed around the hammock ropes by means of strings. The net is suspended from four points, as shown in Fig. 1.65, or from two points if horizontal pieces of wood are used in the roof to keep the two long sides apart. In the latter case the net is suspended from a single string tied between the two hammock rope ends.

Unfortunately, the net is often tight around the hammock, and direct contact between the body and the net or between the lower part of the hammock and net may occur, enabling mosquitos to feed. To avoid this a larger net should be used.

A special military or expedition model for use in jungle areas has the netting attached to the sides of the hammock. At the two ends the hammock is extended with pieces of wood. It is covered by a waterproof roof. Entry is via an opening with a zipper. To prevent mosquitos biting from below, the hammock is made of impenetrable material which also provides insulation from the cold. However, in hot climates these nets trap sweat, making them uncomfortable to lie in.

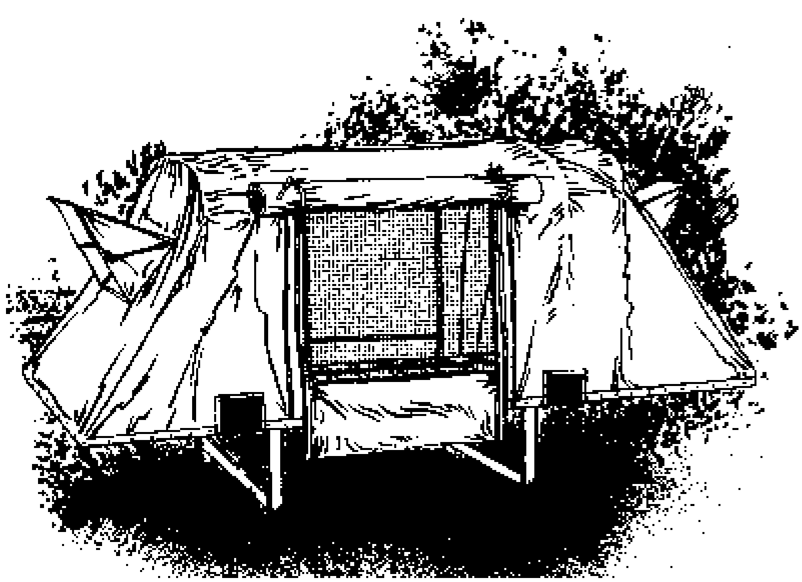


Fig. 1.64. A camp bed with a self-supporting cover gives protection from rain and insects.

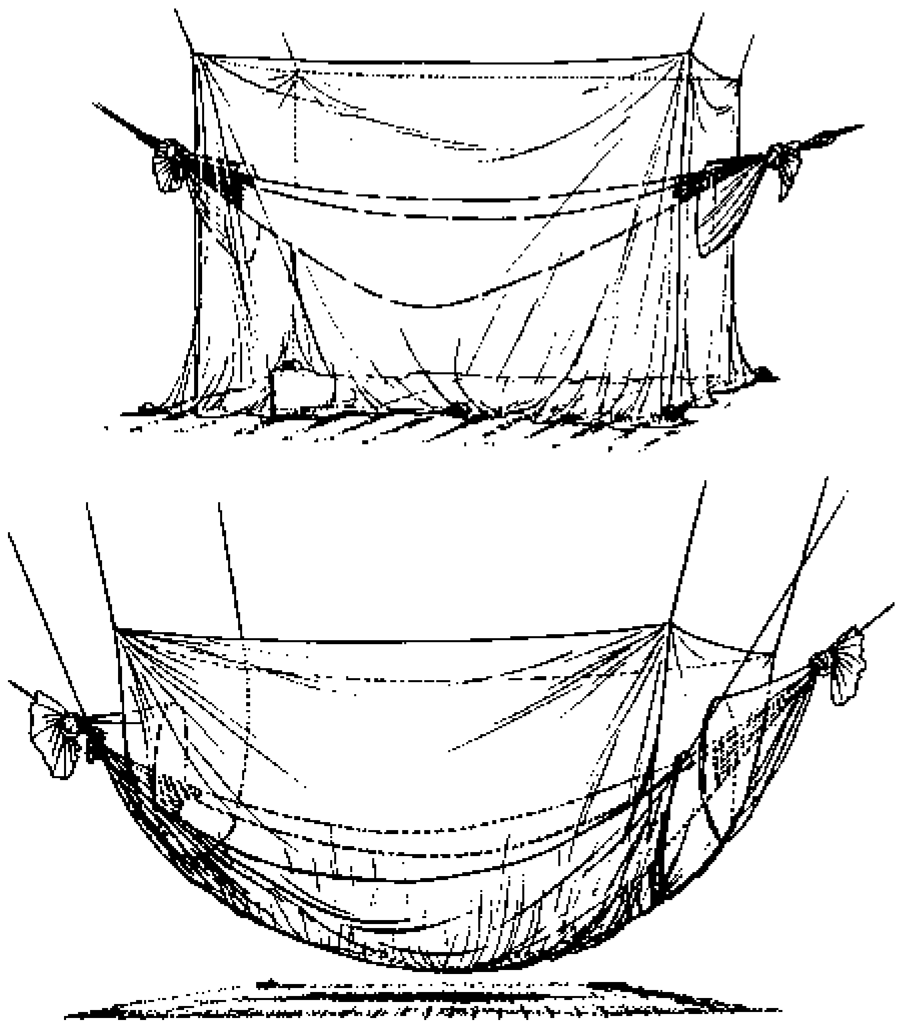


Fig. 1.65. A hammock mosquito net.

Instructions for use of mosquito nets

Any holes developing in the net should be mended as soon as possible. It is important to use a net sufficiently large to cover the entire bed or sleeping place, so that contact between the body and the netting is avoided and mosquitos cannot bite through the net.

In some areas it is customary for several people, especially children, to share one net. This may result in overcrowding, and parts of people's bodies may protrude from the net during the night (Fig. 1.66). A bigger net or an extra one could be used to prevent overcrowding. Alternatively, the net can be impregnated with an insecticide to repel or kill mosquitos before they land on the unprotected skin.

A net can be closed by:

- tucking it in under the mattress or sleeping mat;
- lowering it around the sleeping place until it makes complete contact with the floor; a

border of heavy material ensures good contact, or weights can be put on the border or inserted in the hem to keep it in place.

The net should be let down before darkness falls. Mosquitos that manage to enter can be killed by swatting or by spraying with insecticide before the people concerned go to sleep.

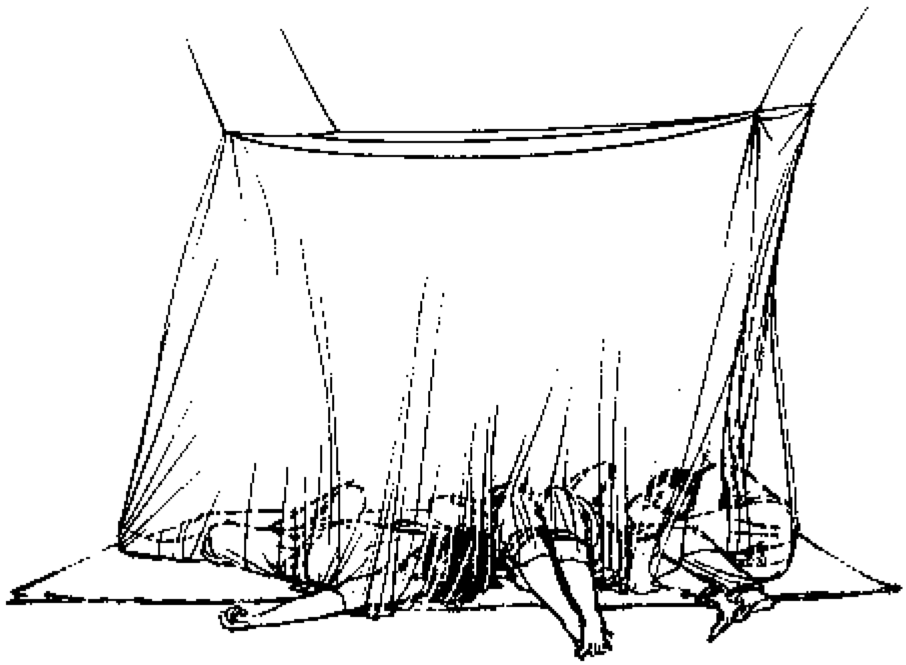


Fig. 1.66. Mosquito nets provide poor protection if shared by too many people.

Open floor with slits

Sometimes mosquitos enter a net from underneath. This problem often occurs in stilt houses with bamboo floors or containing beds with mattresses made of woven string. Sleeping mats can give protection when used with the mosquito net tucked underneath. However, mosquitos may continue to feed through openings in mats that are too thin. A quick-acting safe insecticide on the mat or string mattress may prevent this. This will also help to kill bedbugs. More permanent protection can be obtained by the use of an impenetrable surface under the sleeping mat or the bed. Cloth or plastic sheeting may well serve this purpose.

Obtaining a net

Bednets are widely available in different models, sizes and qualities. They can also be made locally from a length of netting material. The advantage of local manufacture is that quality, design and shape can be chosen to suit personal preferences. Opaque sheeting nets can be made from locally available textiles used in clothing manufacture. Open netting is commonly available as curtain material. Any type of strong opaque sheeting can be used for the borders, ceilings and suspension loops. The seams to which the loops are attached should be reinforced. The durability and effectiveness of cheap factory-produced net can be improved by adding a border to its lower edge.

Problems with mosquito nets

The protection provided by mosquito nets will be reduced if they are not used properly or holes are left unrepaired. In addition, contact may occur with the net during sleep, allowing mosquitos to bite through the net. Furthermore, hungry mosquitos may remain in the room and feed when the occupant leaves the net. They may also be diverted to unprotected people sleeping in the same room (Fig. 1.67).

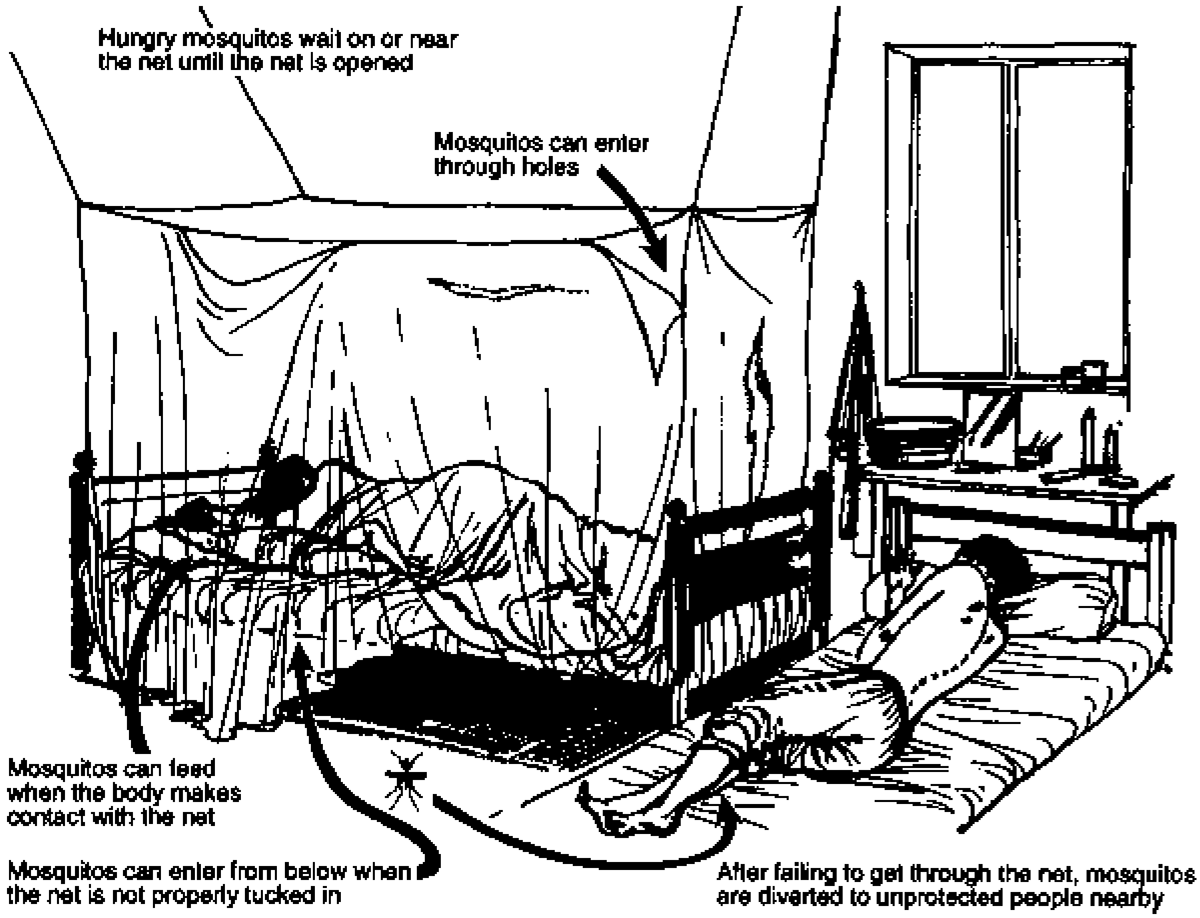


Fig. 1.67. Disadvantages of a standard, untreated mosquito net.

Individual or community protection with untreated nets

If a small number of people in a community use mosquito nets, they will probably benefit because hungry mosquitos can easily find an alternative blood-meal nearby on unprotected people or domestic animals. However, if all inhabitants of a community use nets and there are no attractive domestic animals to feed on, hungry mosquitos are likely to persist until (1) they find holes in nets, (2) they find places where they can feed through nets, or (3) occupants leave nets. In this situation, the use of nets may not result in a reduction of malaria in a community (*73*, *74*). On the other hand, diverted hungry mosquitos can easily obtain blood-meals if there are animals on which they can feed (*75*). In areas where malaria transmission is low or moderate this may be sufficient to reduce malaria among community members.

Insecticide-treated mosquito nets

The above-mentioned problems of standard mosquito nets can be solved by impregnating them with a quick-acting pyrethroid insecticide (*74*, *76 - 78*) which irritates or kills mosquitos on contact, preventing them from finding openings (Fig. 1.68). An impregnated net with holes that are not too large is as effective as an undamaged net (*79 - 81*). Insecticide treatment thus extends the useful life of a net. Mosquitos that land on an impregnated net and attempt to feed through it on part of the body in contact with the net are likely to be killed (*44*). The behaviour of a mosquito that survives contact with the insecticide is so disturbed that it is unlikely to attack again (*79*, *80*, *82*, *83*). People without a net and sleeping near someone with a treated net may receive some protection from bites (*79*). A person leaving such a net during the night or in the morning runs a reduced risk of being bitten.

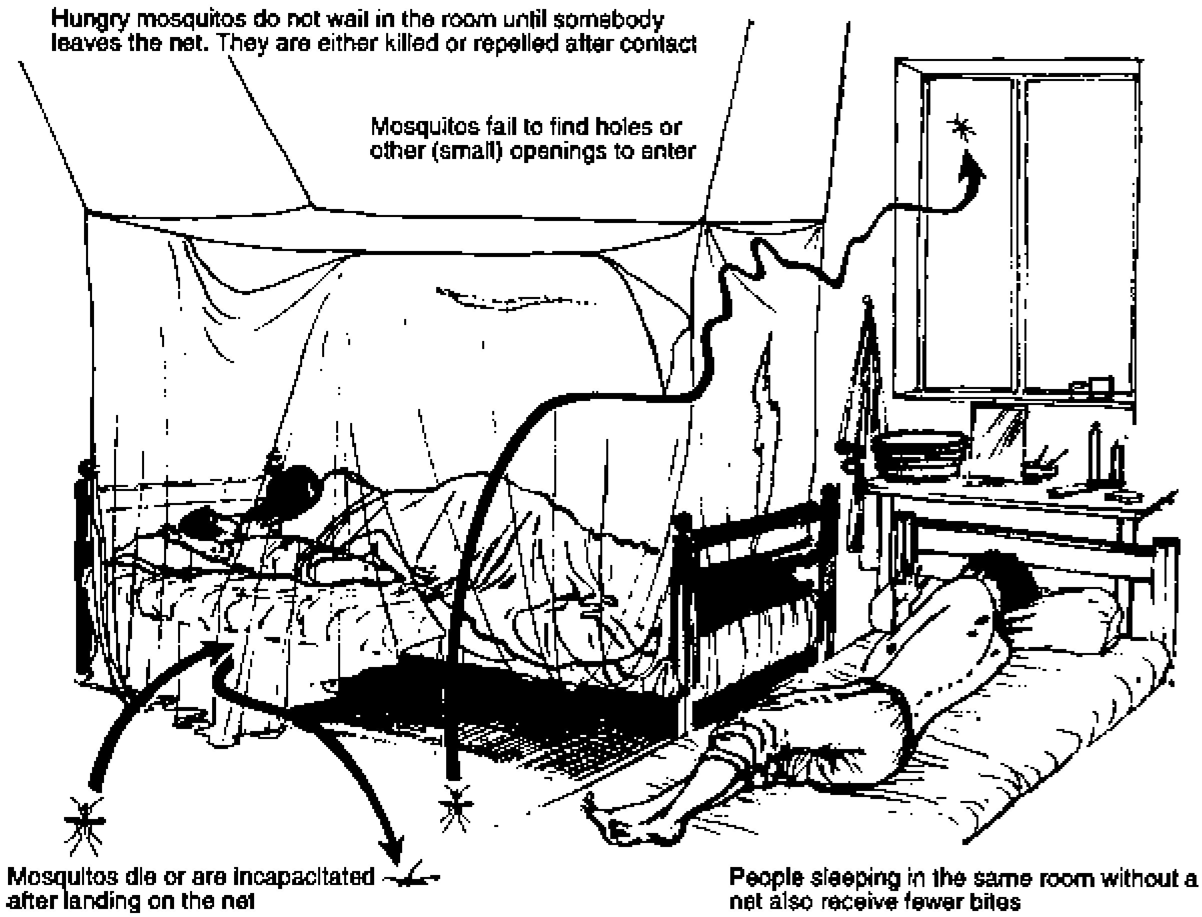


Fig. 1.68. Advantages of mosquito nets treated with an insecticide.

Insecticide-treated nets serve as human-baited traps when somebody is sleeping inside by attracting and killing mosquitos and other biting insects.

These factors make the widespread use of treated mosquito nets particularly important in the control of malaria. When employed by all members of a community the practice kills many *Anopheles* and reduces the chance that any will live long enough to transmit malaria parasites. People outside their nets early in the night or before dawn, or people not using nets, thus receive some protection against the risk of infection (*84 - 88*).

Treated nets can also be used to protect the most vulnerable groups in a community, such as pregnant women, children and old and sick people, from infection with malaria or other insect-borne diseases. Young children, going to sleep early, receive most protection (*89*).

The use of impregnated bednets may lead to the disappearance or reduction of other pests that are sensitive to the insecticide used, such as bedbugs, head lice, chicken ticks and houseflies (*90*, *91*). The nets are probably also effective against fleas and triatomine bugs.

Which nets can be treated?

All types of bednet are treatable, including old nets with holes and nets of synthetic or natural fibre. However, multifilament nets are better than monofilament nets at holding the insecticide. The insecticide particles are easily dislodged from monofilament nets by abrasion or washing. For more information on the insecticides that can be used and on how nets should be impregnated see p. 85.

Control of malaria in a community with treated nets

Insecticide-treated bednets have been successful in reducing the number of malaria infections in villages where the transmission of malaria is low or moderate, for instance in China and the Gambia (*88*, *92*). In villages where the transmission of malaria is intense (holoendemic malaria), community use of impregnated mosquito nets was found to have little impact on the number of infected people. However, people received 90 - 95% fewer infective bites from malaria-carrying mosquitos, and were apparently better able to overcome the disease and to develop immunity (*76*, *85*, *93 - 96*).

Alternative materials for treatment

Other materials, such as fabrics of wide-mesh netting and bed curtains made of loose single-strand fibres, can also act as a physical barrier to the entry of insects, if treated with insecticide.

Wide-mesh nets

Treated nets with a mesh size slightly less than the wing span of a flying insect will force it to land before passing through, and on contact with the net it will be killed or repelled (*97 - 102*). Treated netting with a mesh size of approximately 4 mm protects against most mosquito species (*81*) and a mesh size of 2 mm would probably be effective against biting midges and sandflies (*103*). Such nets allow good ventilation in hot climates.

The advantages of wide-mesh nets (*74*) include:

- increased ventilation in hot and humid climates;

- reduced cost, even though stronger fibre is required;

- weight and volume when folded are less, making the nets easy to distribute and practical for travellers and nomadic people.

The disadvantages of such nets are:

- the nets offer no protection once the insecticide has lost its activity; prompt re-treatment is particularly important with this type of net;

- wide-mesh nets are more easily torn than standard nets;

- they are not yet commercially available but can be made out of curtain or other wide-mesh netting material.

Bed curtains

In areas where bednets are too expensive an alternative may be to use curtains made of locally available fibres (Fig. 1.69) or strings hung around the bed. To offer protection from flying insects these open curtains must be treated with an insecticide. A roof is not essential as mosquitos generally fly low. Curtains offer considerable protection but are not as effective as treated bednets.

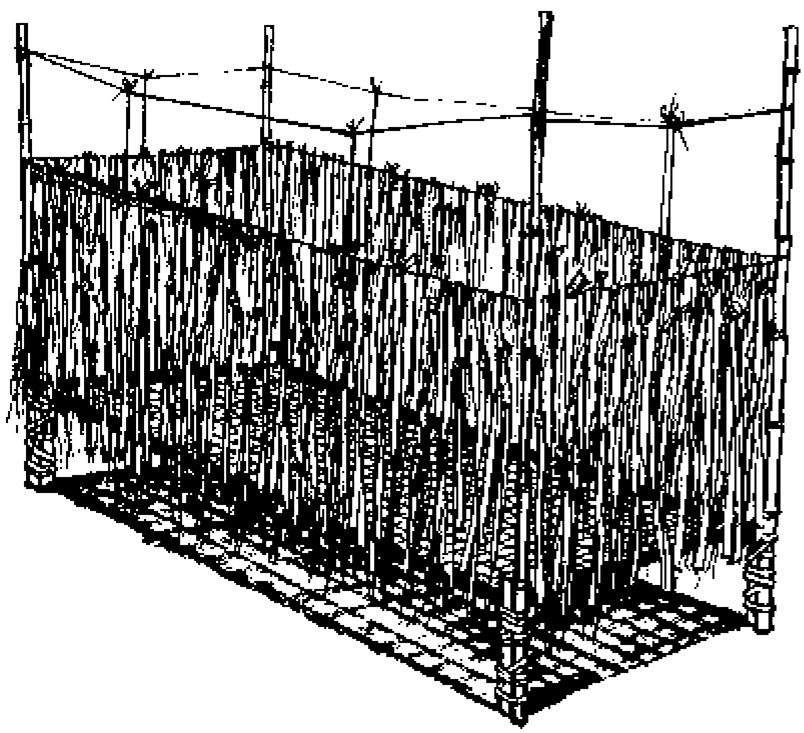


Fig. 1.69. A cheap alternative to mosquito nets may be bed curtains made of locally available fibre material treated with an insecticide.

Suitable materials include fibres from polypropylene or jute sacks. Sacks should be cut open and unpicked to obtain a loose arrangement of fibres. Flammable material (e.g. sisal) should not be used.

Treating fabrics with an insecticide

The impregnation of fabrics with an insecticide is simple: an emulsion is made in water, and the material to be impregnated is soaked in it and allowed to dry. After drying, the insecticide remains attached to the fibres.

Insecticides1

[1] Further information on insecticides is available on request from Division of Control of Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland.

Many well known insecticides, e.g. DDT, are not suitable for the treatment of fabrics because they act too slowly and allow insects to make contact and escape before they pick up a lethal dose. Moreover, many insects have developed resistance to a number of insecticides. The synthetic pyrethroids do not have these disadvantages. They are quick-acting and highly toxic to insects. In addition, they are considered to be generally safe to humans at the recommended dosages. They are also relatively safe for the environment because of their quick breakdown in the soil.

Pyrethroid insecticides are available as solutions, usually called emulsifiable concentrates. These can be mixed with water, producing a milky liquid. Oil-in-water emulsion formulations have been made specially for the treatment of fabrics; they give good adherence of the insecticide to the fabric material and do not produce an unpleasant odour during treatment. Pyrethroids can also be obtained as wettable powders or suspension concentrates, also known as flowable concentrates, but these formulations are less suitable for treating fabrics since they are more easily dislodged. This reduces the period of effectiveness and the dislodged particles may cause irritation of the skin. A number of photostable pyrethroids are available, of which only permethrin, cyfluthrin, deltamethrin and lambdacy-halothrin have been tested for their efficacy and safety in the treatment of mosquito nets. Permethrin and flumethrin have been tested for the treatment of clothing.

Pyrethroids for treatment of fabrics

Not all pyrethroid insecticides are suitable for the treatment of fabrics. To be suitable, a pyrethroid must remain effective in the fabric for at least several weeks, be resistant to sunlight and safe. The first-generation pyrethroids, such as the natural pyrethrins (pyrethrum), the allethrins and phenothrin, are unsuitable because they decompose rapidly when exposed to daylight. The second- and third-generation pyrethroids are much more stable and are therefore suitable (*104*).

Permethrin

Permethrin is commonly used for agricultural and public health purposes and is widely available. It is the most commonly recommended insecticide for the impregnation of bednets and clothing. It has proved to be highly effective in pest control, and there are no reports of adverse side-effects.

Deltamethrin

Deltamethrin is commonly used in agriculture and public health and is widely available.

This pyrethroid is used extensively in China for the impregnation of bednets. It is more than 30 times as powerful as permethrin. Recommended dosages are much lower than for permethrin but this is compensated by a higher price per unit weight. The toxicity to domestic animals and humans is higher than that of permethrin, but formulations contain less active ingredient. There have been complaints about an irritant effect during the impregnation procedure. People sleeping under dry nets do not usually experience any side-effects but this may depend on the fibre material of the net and the insecticide formulation. A burning sensation of the face has been reported by people sleeping under polyethylene nets treated with a flowable formulation of deltamethrin (C.F. Curtis, unpublished observations, 1990) and by people sleeping under cotton nets treated with deltamethrin wettable powder (*105*).

Lambdacyhalothrin

This insecticide has been developed recently and is increasingly used for public health purposes. It is widely available for agricultural use. In general its properties are similar to those of deltamethrin. It is reported that lambdacyhalothrin causes nasal irritation to some people sleeping under freshly treated nets, even when these are dry. Reports demonstrating its prolonged insecticidal effectiveness have recently become available (*93*, *106*) and more trials are under way.

Cyfluthrin

This product is used in agriculture and public health and is widely available. It is more toxic to insects than permethrin but less toxic than lambdacyhalothrin and deltamethrin. No side-effects have been reported but testing has been very limited so far (G. Hesse, personal communication). A special oil-in-water emulsion is available which gives better adherence to fibres than the emulsifiable concentrate formulation and does not produce an odour or irritant effect during treatment.

Other pyrethroids

The toxicities of cypermethrin, flumethrin and alphacypermethrin range between those of permethrin and deltamethrin. However, these insecticides have not yet been fully tested for efficacy and safety in the treatment of mosquito nets or clothing.

Optimal combination of mosquito net materials and pyrethroids

For the same insecticidal effect, nets made of cotton fibre need to be impregnated with 3 - 5 times as much permethrin or lambdacyhalothrin as those made of nylon fibre (*107*, *108*). This may be because in cotton fibres much of the insecticide is contained in the hollow spaces inside the fibres where it is unavailable to mosquitos. Nylon fibres are not hollow and most of the insecticide remains on the outer surface, where landing mosquitos pick it up on their legs. However, with deltamethrin there seems to be no difference in effectiveness between cotton and nylon (*77*, *108*).

Before a choice of material is made the local availability of materials should be investigated. The choice will then depend on a comparison of costs and technical considerations.

Recommended dosages

The recommended dosages of insecticide per quantity of fabric are usually given in grams of active ingredient per square metre (g/m^2) or in milligrams of active ingredient per square centimetre (mg/cm^2) ($1\ g/m^2 = 0.1\ mg/cm^2$).

If impregnated with the same mixture of insecticide, a square metre of thick fabric absorbs much more insecticide than a similar area of thin open-weave fabric. However, some of the insecticide is not available on the surface, having penetrated inwards. Higher dosages of insecticide per unit area of thick fabric are presumably needed to provide a toxic resting surface equivalent to that obtained on the thinner fabrics (Table 1.3).

The duration of activity of an insecticide would normally be expected to be longer with a higher dosage. However, if a fabric is washed regularly it may be advisable to treat it with a lower dosage after each wash.

The more potent pyrethroids may be more economical because of the lower dosages needed. However, prices per unit weight of these insecticides are higher than that of permethrin and the choice will depend on local availability and prices.

Table 1.3. Dosages of insecticide needed to impregnate different types of fabric

Fabric	Dose (g/m^2)			
	Permethrin	**Cyfluthrin**	**Deltamethrin**	**Lambdacyhalothrin**
Wide-mesh netting (more than 2 mm)	0.10-0.25	0.05	0.008-0.012	0.005-0.008
Standard mosquito mesh (1.5 mm)	0.20-0.50	0.03	0.01-0.025	0.010-0.015
Cotton cloth (sheeting, shirts)	0.70-1.20	0.05	-	-
Thick fabrics, jackets, trousers	0.65-1.25	0.05	-	-

Safety measures

Pyrethroid insecticides recommended for treatment of mosquito nets are relatively non-toxic to humans, mammals and birds. A distinction should be made between safety for people using treated fabric and safety for people who carry out the treatment. Fabric treated at the recommended dosage is not hazardous after drying.

During treatment the insecticide mixture should not come into contact with the skin, particularly the lips, mouth, eyes and any open wounds. Rubber gloves should be used during the treatment process, and care should be taken to avoid splashing solution into the eyes and inhaling fumes. When many treatments are to be done it is better to work outdoors or in a well ventilated space and use open, shallow containers.

People who inhale the fumes of the insecticide mixture may develop a headache or irritation of the nose or eyes. This occurs more frequently with deltamethrin or lambdacyhalothrin than with permethrin or cyfluthrin. A tingling sensation in the skin of the hands may be felt when treatment is carried out without gloves. These side-effects disappear within a few hours. If the eyes are contaminated or the skin shows an irritant reaction, the affected part should be rinsed thoroughly with clean water. Medical advice must be sought if pyrethroids are swallowed.

Safety of treated nets

After drying, care should be taken to prevent small children who sleep under a net from putting part of it in their mouths. Synthetic nets (nylon, polyester) freshly treated with a relatively high dose (0.030 g/m^2) of lambdacyhalothrin may cause cold-like symptoms, such as sneezing and a runny nose during the first 1 - 2 weeks of use. At the lower dosage of 0.010 g/m^2, which still has a prolonged insecticidal effect, the side-effects last only a day (*93*). No side-effects have been reported with synthetic or cotton nets treated with permethrin or with cyfluthrin as an oil-in-water emulsion.

How to prepare the appropriate solution and treat and dry the fabric

The fabric to be treated should first be thoroughly cleaned or washed if it is dirty; it should be completely dry by the day of treatment. This is of special importance when bednets belonging to different people are impregnated in the same mixture. When several nets are treated at the same time, they should be marked with a waterproof marker to allow each to be returned to its owner.

1. Calculate the surface area of the fabric to be treated (Fig. 1.70).

2. Determine the amount of water needed to completely soak the fabric (Table 1.4):

- Partially fill a bowl or bucket with a known quantity of water (Fig. 1.71).

- Soak the fabric in the water.

- Wring it out gently and/or allow it to finish dripping, collecting the run-off in the container.

- Measure the difference between the initial and the remaining amount of water. You can do this with a large measuring cylinder, or by finding the difference in weight of fabric before and after soaking and dripping. The difference in grams is equal to the number of millilitres (ml) of water absorbed by the fabric. This gives the amount of water needed to prepare the solution.

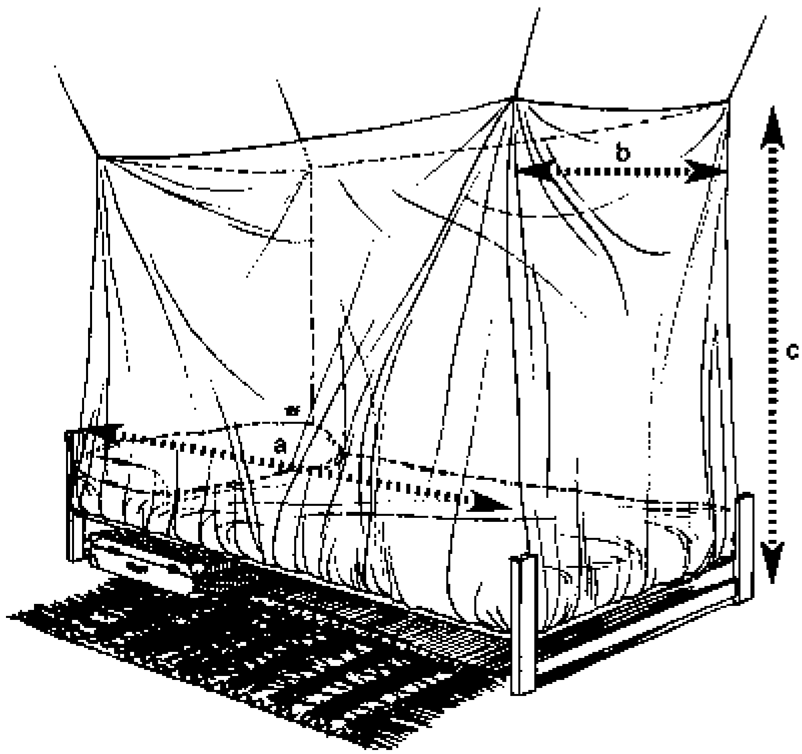


Fig. 1.70. The surface area of a rectangular bednet is calculated using the formula: $S = 2(a \times c) + 2(b \times c) + (a \times b)$.

3. Prepare the solution for treatment:

- Calculate the total weight of insecticide needed (T) as:

$T = D \times S$

where
D = the chosen dosage (g/m^2)
S = the total surface area of fabric (m^2).
The amount of insecticide concentrate needed to prepare the solution (I) can be calculated as follows:

$I = T/C$
where

C = the amount of active ingredient in the insecticide concentrate (g/ml).

For example, 25% emulsifiable concentrate contains 25 g per 100 ml, thus 1ml contains 0.25 g of active ingredient. Measure out the volume needed with a small measuring cylinder or pipette (Fig. 1.72).

- Measure out the required quantity of diluting water with a large measuring cylinder (or measuring can), as calculated in step 2.

- Mix the emulsifiable concentrate with water in a suitable container.

Table 1.4. The quantity of water absorbed by different types of netting material and the amount of permethrin required to treat netting at a rate of 0.5 g/m^2 [a]

Quantity of netting material	Amount of water (ml)			Amount of 10% permethrin (ml)	Amount of 25% permethrin (ml)	Amount of 55% permethrin (ml)
	Polyethylene netting	Nylon/ polyester netting (den. 100/ mesh 156)	Cotton netting			
1 m^2	14	30	130	5	2	0.9
1 net (12.5 m^2)	175	375	1625	62.5	25	11.5
4 nets	700	1500	6500	250	100	45.5
12 nets	2100	4500	19500	750	300	136.5
20 nets	3500	7500	32500	1250	500	227.5

[a] This table is based on field data from Dr R. Montanari, WHO, Papua New Guinea and from Dr C. Curtis, London School of Hygiene and Tropical Medicine, London, England.

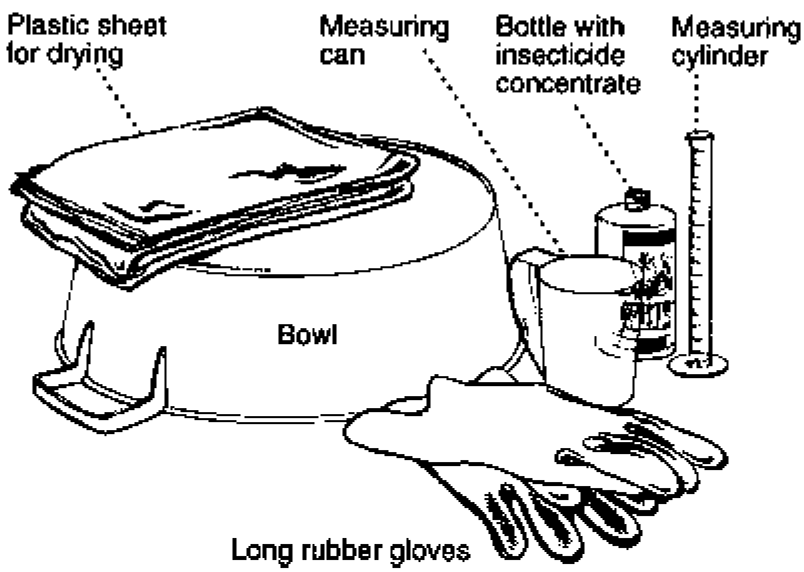


Fig. 1.71. Utensils and equipment needed for treating fabrics with insecticide.

Fig. 1.72. Pouring emulsion concentrate into a measuring cylinder.

To make sure the fabric is completely impregnated, it may be advisable to prepare some excess mixture. The excess, as well as the run-off liquid after wringing out, can be reused to impregnate other fabrics.

4. After calculating the amount of water absorbed (step 2), dry the fabric. Submerge the clean dry fabric in the mixture, pressing and squeezing thoroughly to remove air and make sure the fabric is completely soaked (Fig. 1.73). Large articles such as bednets should be folded into a neat package to facilitate removal of air and penetration of the mixture. This is especially important with stiff, non-elastic bednets made of polyethylene.

The container in which the articles are treated should be large enough to allow them to be handled and turned over without spilling the mixture. Buckets, dustbins, washing-up bowls or plastic bags may be suitable, depending on the number and size of the items to be treated. If a plastic bag is used, it should be filled with the amount of mixture needed to saturate the fabric without leaving any excess. After putting the item into the bag, seal the top by tying or twisting. Shake and knead the bag vigorously for 10 minutes (Fig. 1.74). Then remove the fabric and allow to dry without wringing it out.

5. Take the wet item out of the treatment container, gently wring out any excess liquid or allow it to drip back into the container. Place the fabric on a plastic sheet or other clean, non-absorbent surface to dry, e.g. banana leaves (Fig. 1.75). If a plastic bag is used for treatment it can be cut open to make a drying sheet. During the drying process the fabric should be turned over from time to time. The drying time depends, among other factors, on the thickness of the fabric, the quantity of water absorbed and the surface area exposed to sun and wind. A cotton mosquito net takes several hours to dry. Exposure to bright sunlight may partially destroy pyrethroid insecticides, so it is preferable to keep wet fabrics away from sunshine.

Generally, items should not be hung up to dry immediately because insecticide will be lost as a result of dripping and will spread unevenly in the fabric. When they have been drying for some time on the ground they may then be hung up to speed up the process

(Fig. 1.76). Cotton is less likely than synthetic materials to drip when hung up to dry after being wrung out.

Fig. 1.73. Treatment of a fabric by pressing and soaking. Rubber gloves should be used to protect the hands.

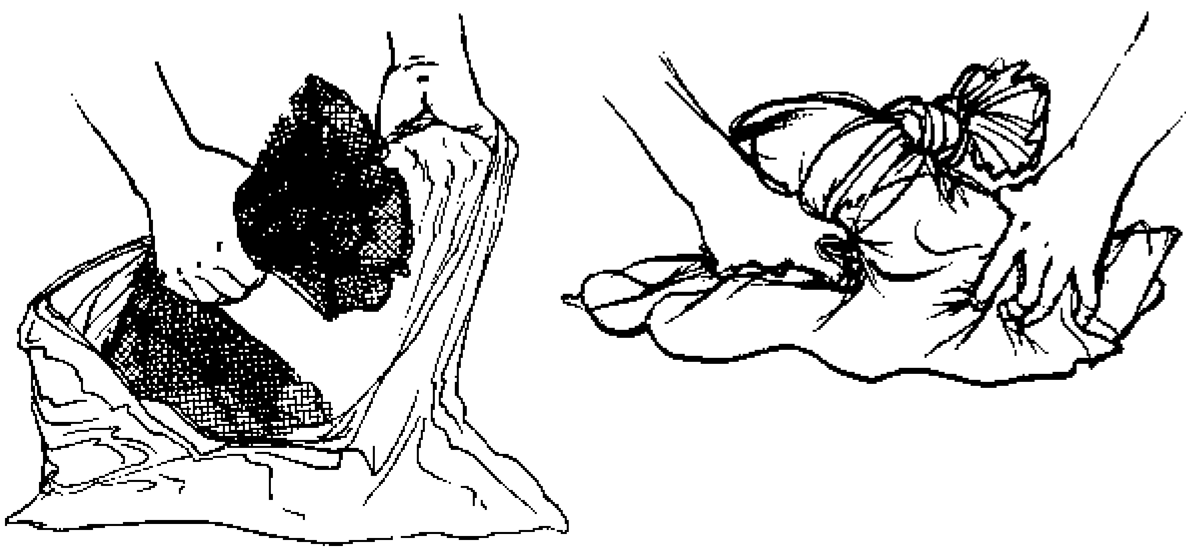


Fig. 1.74. Impregnation of fabric in a plastic bag.

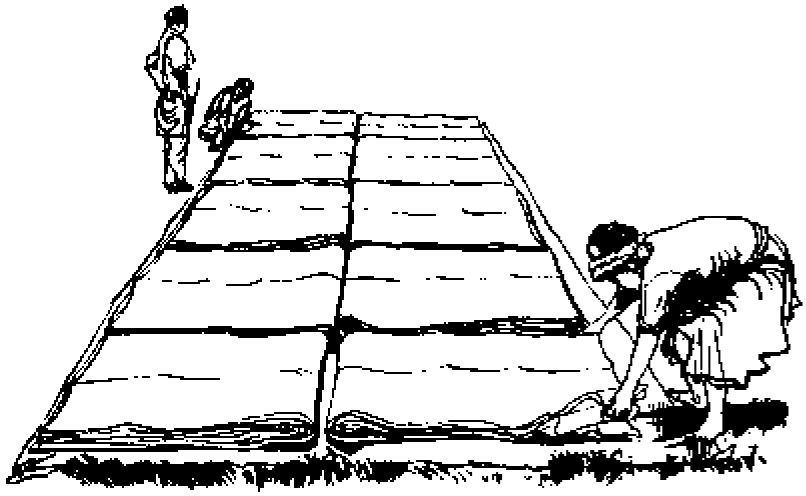


Fig. 1.75. Dry the treated material on a plastic sheet or other clean nonabsorbent surface, avoiding direct sunshine.

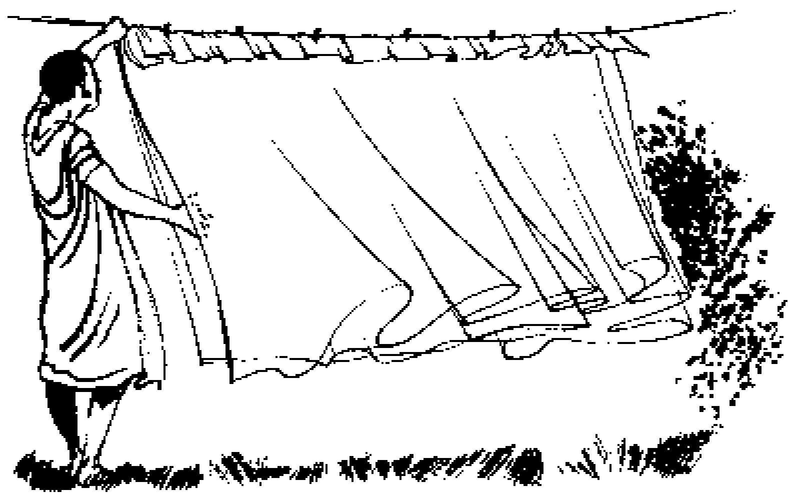


Fig. 1.76. When a freshly impregnated fabric has been drying for some time on a horizontal surface, it can be hung up to speed up the process.

In some instances a gradient of insecticide in a fabric may be useful, for example in hammock nets because the lower part is where the net comes into contact with the body (see p. 72). Such a gradient can be achieved by hanging up the item at an early stage in the drying process (Fig. 1.77).

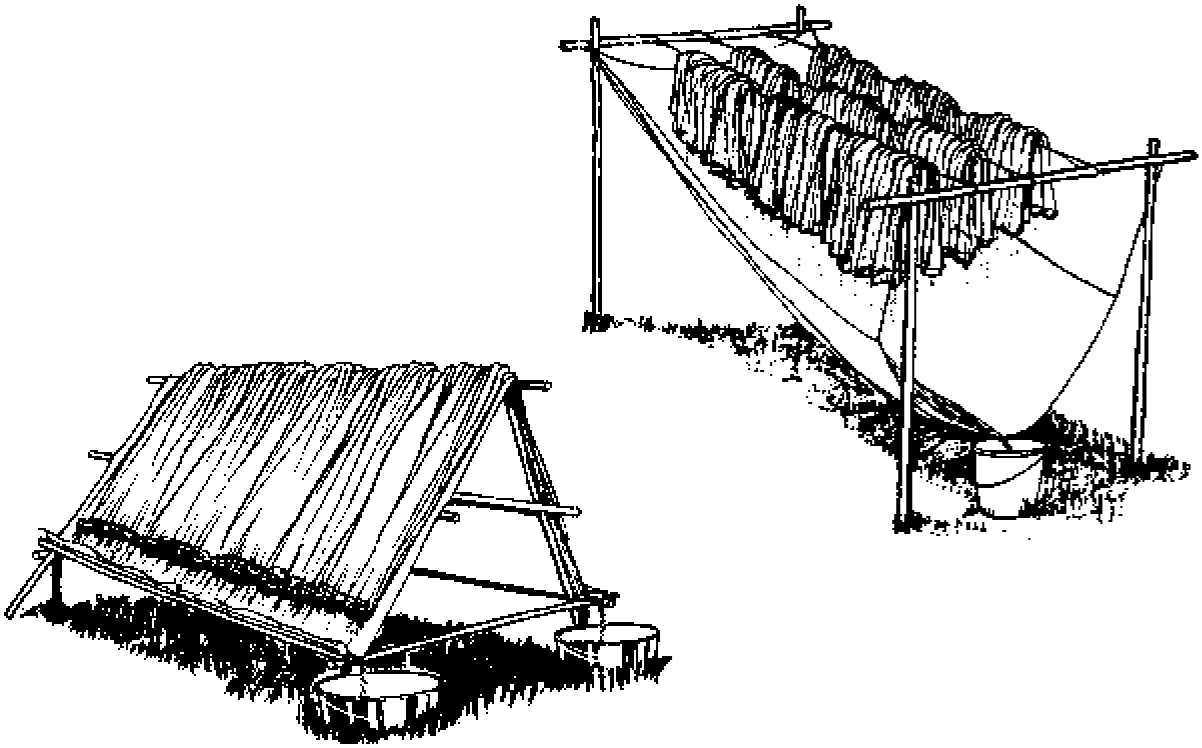


Fig. 1.77. Devices made of poles and plastic sheeting for large-scale treatment of mosquito nets. Bowls collect the excess liquid running down from a plastic sheet (design: S. Meek).

To treat a single (rectangular) net
To treat a single family-size (12.5 m^2) mosquito net made of nylon/polyester material at 0.5 g/m^2, mix 375 ml of water with 25 ml of permethrin 25% emulsifiable concentrate. Stir the mixture and pour it into a plastic bag. Put the net into the bag and seal it by tying or twisting. Shake and knead the bag vigorously for 10 minutes (see Fig. 1.74). Then remove the net and place it on the bag (cut open to make a sheet) to dry.

To treat 20 nets
To treat 20 standard family-size (12.5 m^2) mosquito nets made of nylon/polyester material at 0.5 g/m^2, fill a plastic dustbin with 7.5 litres of water and 500 ml of permethrin 25% emulsifiable concentrate. Stir the mixture and add the nets one by one, immersing and pressing them until completely saturated. Make sure you wear gloves. Take the nets out of the solution, allow to drip, and dry flat, preferably in the shade, on a plastic sheet.

Spray-on application

Spray-on application of insecticide (Fig. 1.78) may be preferred for the large-scale treatment of fabrics (*74*).

The advantages of such application are:

- quick application and quick drying;

- for thick fabrics, application on only the outer surface may reduce losses of insecticide by inward penetration;

- less insecticide is used if it is applied only to the parts where contact with insects is likely to occur;

- suitability for quick mass treatment of nets in villages, where some people may object to their nets being washed or impregnated together with other nets in one container.

The disadvantages are:

- need for spraying equipment;

- some training is needed to make sure the correct dosage is applied;

- a considerable quantity of insecticide may be lost to the atmosphere.

Spraying equipment

Pressurized spray cans

Spray cans containing permethrin (0.5%) or flumethrin are available; they are convenient but expensive. One can containing 85 g of permethrin is sufficient for the treatment of only 3.5 - 4.5 m^2 of fabric, because much insecticide is lost to the atmosphere during spraying.

Hand-compression sprayers

Several models exist which are widely used in malaria control programmes. These sprayers are suitable for the application of a mixture of insecticide in water.

Electro-hydrodynamic sprayers

These sprayers were developed for spraying specially prepared solutions of pyrethroids without pressure. No water has to be added and the fabrics dry quickly. Because the droplets are electrically charged they are attracted to electrically grounded material; the spraying of wide-mesh netting is therefore possible.

How to spray a fabric

Method 1. The procedure for the dilution of insecticide is as follows. Samples of fabric with a known surface area are sprayed with water by moving the spray nozzle at constant speed and distance from the fabric (see Chapter 9).

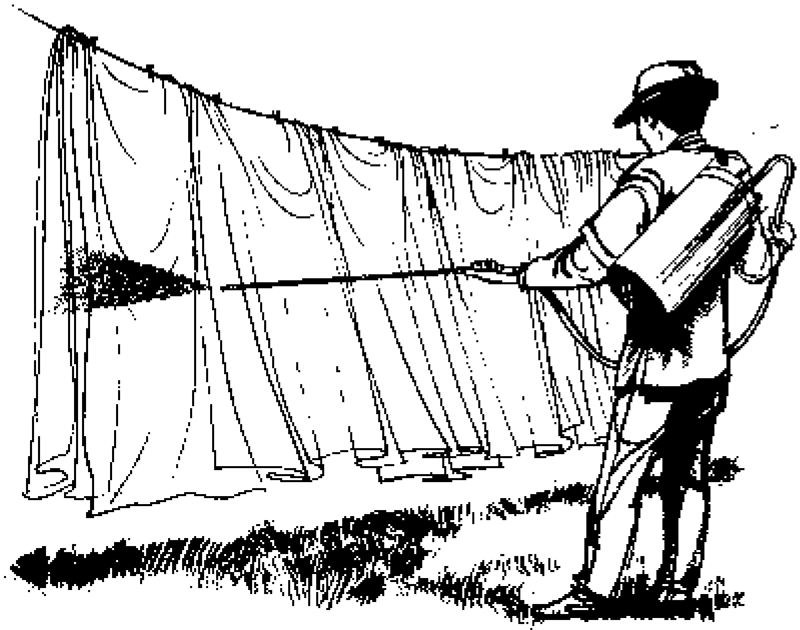


Fig. 1.78. Applying insecticide to a mosquito net with a hand-compression sprayer.

By adjusting the speed of movement of the nozzle it is possible to avoid dripping and ensure quick drying. The water consumption is measured from the reservoir of the pump. The solution can then be prepared as explained on p. 88. It is important to spray the side that will be exposed to insects because the other side may acquire less insecticide. Following this procedure, fabrics for spraying can be suspended from a line to which they can remain attached for drying.

Method 2. Spray thin fabrics and netting material to the point of run-off (full saturation) with an insecticide solution made up as described on p. 88. A plastic sheet should be hung behind the fabric to be sprayed to collect excess solution. It is also possible to hang the nets, one by one, on a dripping device for spraying (see Fig. 1.77).

When to re-treat

Fabrics must be re-treated when the insecticide has lost its strength. Loss in effectiveness occurs for the following reasons.

- The insecticide slowly degrades or evaporates, processes that are accelerated by exposure to direct sunlight.

- Insecticide leaches out on exposure to rain.

- Washing causes loss of insecticide.

- Frequent handling and daily folding up of nets causes loss of insecticide.

To extend the period between treatments, it is important to:

- avoid unnecessary handling of treated fabrics;

- treat fabrics soon after washing, so that they will not need to be washed again for some time after treatment;

- store the fabric in a plastic bag or box (this avoids both deterioration of the insecticide and the accumulation of dust);

- use alternative methods of cleaning, e.g. shaking or brushing with a soft brush; if washing cannot be postponed, the fabric should be washed in cold water without using soap;

- use coloured nets that do not show dirt and dust;

- time treatments in accordance with the seasonal patterns of biting and disease transmission.

Approximate duration of residual efficacy of permethrin (*74*)	
Unused mosquito net	>6 months (1-2 years in airtight bag)
Mosquito net used daily	4 - 6 months
Net used daily and washed after 1 month in	2 - 3 months
cold water	
Net used daily and washed weekly in cold water	1 month
Clothing worn daily and washed weekly	1 - 2 months

Measuring residual efficacy

Reduced effectiveness can sometimes be observed by an increase in numbers of biting insects and the survival of insects that make contact with treated fabrics or bednets. If impregnation is primarily aimed at controlling certain species of mosquito, it is their survival that should be observed.

Re-treatment is needed when:

- mosquitos manage to enter a bednet and stay alive;
- bloodsucking insects manage to feed through treated material and stay alive after walking, crawling or resting on it.

In many cases the loss in effectiveness is difficult to observe. However, if transmission is seasonal it is usually sufficient to treat the net once a year at the beginning of the transmission season. Where there is insect-borne disease it is very important not to wait until the treated fabric loses its protective action before retreating. Several simple methods are available for measuring residual effectiveness (Fig. 1.79). Tests should be conducted on freshly impregnated fabrics, to obtain baseline results for comparison with later tests. Each test should be repeated several times.

• **Release in mosquito net**. This is a simple but inaccurate test that does not require any special materials other than those needed to collect live mosquitos. Hang the net in such a way that it makes contact with the floor and put a white sheet underneath.

Collect 50 mosquitos and release them in the net. After 15 minutes, enter the net and collect the mosquitos; record the number dead and alive. Re-treatment is needed when fewer than 16 of the mosquitos are killed, and no mosquitos have been observed resting on the sheet. If mosquitos do rest on the sheet, the test is invalid and must be repeated. Resting on the sheet can be avoided by closing the net from below for the duration of the test.

• **Petri dish method**. This method is suitable for all kinds of fabric and for many types of biting insect. Invert a flat transparent container, such as a Petri dish without a lid, over the treated fabric (Fig. 1.79a). Collect live insects of the species against which protection is sought and confine them in the space between the fabric and the container. Measure the time required to knock down or kill at least 80% of the insects. Thus if five successive batches of 10 mosquitos are exposed and the average time for the eighth mosquito to fall down is six minutes, this is the knock-down period for 80% of the mosquitos. If the test is repeated several months later and the time required to obtain 80% knock-down is much longer, say 60 minutes or more, then it can be concluded that the fabric should be re-treated.

• **Bioassay cone method**. This method, recommended by WHO (*78*), requires special equipment and training. The cone can be attached to the fabric with a rubber band (Fig. 1.79b) or by pinning it to a piece of wood or cardboard held under the fabric. If unwoven fibres or wide-mesh material are used, the cone can be applied to a pad of the material made by folding it several times. Expose 10 mosquitos at a time for about three minutes. Then, remove the mosquitos and transfer by means of an aspirator (Fig. 1.79c) to a clean paper or plastic cup which is screened and contains a piece of cotton soaked in 10% sugar water. Record the numbers knocked down at 1 hour and 24 hours after exposure.

Repeat the test five times, so that 50 mosquitos are tested. The insecticide is considered to be still effective if at least 40 of the exposed mosquitos (80%) have been knocked down. Because mosquitos might die as a result of rough handling or poor condition, a control test should be carried out in a similar way, but with the mosquitos exposed to untreated netting. If the mortality in the control group is over 20%, the test should be repeated.

Determination of the residual effectiveness of a treated bednet:

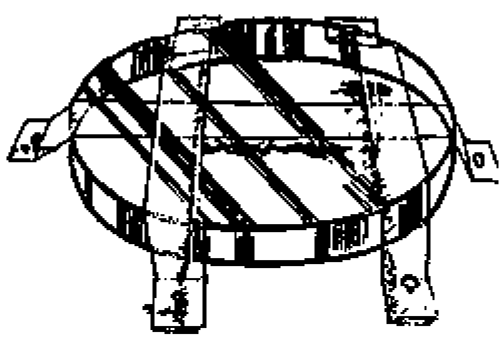


Fig. 1.79.(a) Petri dish method;

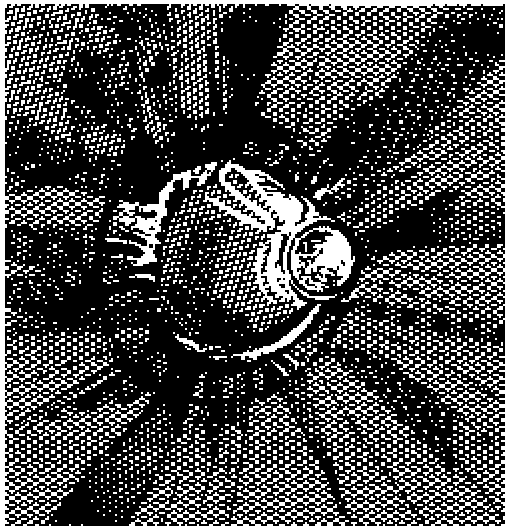


Fig. 1.79.(b) bioassay cone method;

Fig. 1.79.(c) removing mosquitos from a bioassay cone by means of an aspirator.

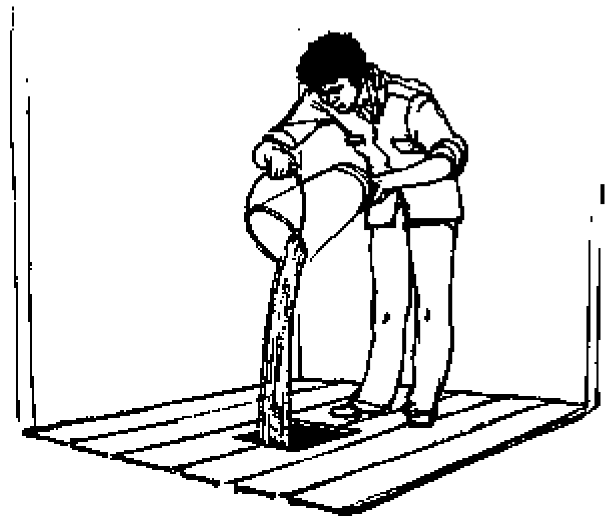


Fig. 1.80. Surplus insecticide can be disposed of safely by pouring it into a pit latrine or a specially dug hole in the ground.

Disposal of insecticide1

[1] See also Chapter 10.

Insecticide solution can be used for reimpregnation for a few days after preparation. Any solution remaining after this time should be disposed of carefully. It should not be disposed of where it may enter drinking-water, washing-water, fish ponds or rivers, as pyrethroids are very toxic to fish. It should be poured into a specially dug hole in dry ground where it will be absorbed quickly, degraded and will not cause any environmental problems (Fig. 1.80). The solution may also be used to treat sleeping-mats or string mattresses to prevent mosquitos from biting from below. Where bedbugs are a problem, mattresses can be treated. Surplus solution can be used for killing insect pests such as ants and cockroaches; it should be poured or sponged on to infested places (under kitchen sinks, in corners). Insect breeding can be temporarily reduced by pouring solution in and around latrines or similar places.

Making houses and shelters insect-proof

Many mosquitos attack people at night inside houses. To a lesser extent, biting midges and, in some dry areas, sandflies also enter houses to bite. Methods that restrict or prevent the entry of mosquitos into houses offer significant protection to the inhabitants.

Methods that prevent entry or kill insects that have entered include the use of aerosols, mosquito coils, vaporizing mats and repellent smoke. With all of these methods there is the disadvantage that there is no residual effect. In addition to bednets, more permanent solutions that are more effective, convenient and longer-lasting are needed.

House design

Relatively few mosquitos enter houses built on poles, or apartments above the ground floor, because many species prefer to fly close to the ground (*109*). However, mosquitos have sometimes been found high in apartment blocks, e.g. in Calcutta (*110*).

Fewer and smaller openings in a house also mean that fewer mosquitos enter. In tropical areas, ventilation openings such as windows and eaves provide easy access to flying insects, although some mosquito species are less likely to find the openings and enter the house than others (*111*). Openings not needed for ventilation should be closed when possible (*112*). Blocking the eaves may be unacceptable because of the restriction on ventilation. However, screening the eaves is a good idea (see below). Doors and windows should fit and close properly. Only modern air-conditioned houses can be kept completely closed at night in hot areas.

If eaves cannot easily be blocked or screened, a ceiling may be constructed to stop mosquitos entering the living quarters. If a solid ceiling is too heavy for the house structure, a lightweight ceiling of hessian-type cloth, woven (matting) material or mosquito netting can be constructed (Fig. 1.81). In houses with corrugated iron roofs, ceilings offer the added benefit of partial insulation from heat radiated from the roof. However, a disadvantage of a solid construction is that it may provide a habitat for small mammals, birds and snakes and, in South America, for triatomine bugs, vectors of Chagas disease (*113*, *114*).

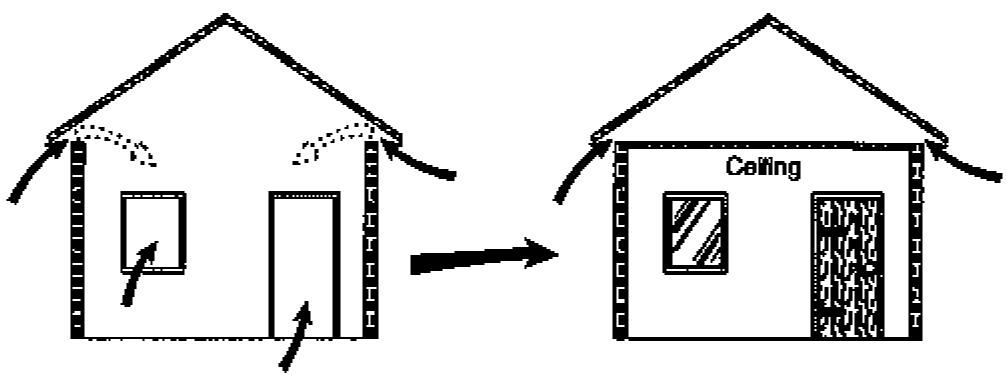


Fig. 1.81. Mosquitos can enter houses in the tropics through the eaves. A lightweight ceiling not only prevents this but also offers some insulation from heat radiated from the roof (© WHO).

Anti-mosquito screening

Screening of doors, windows and other openings in houses prevents insects from entering, while maintaining some ventilation. To stop most mosquito species, the openings in the netting should be 1.5 mm or less. To stop sandflies or biting midges the openings must be much smaller. Screening is often unacceptable because of the restriction on ventilation. However, it is commonly used in areas where mosquitos and mosquito-borne diseases are a problem throughout the year and where artificial ventilation is available.

Screening can be fitted permanently to the openings of a house or put on frames to make it removable (Fig. 1.82). The latter is more expensive and requires skilful fitting.

Screening should be regularly inspected for tears and holes.

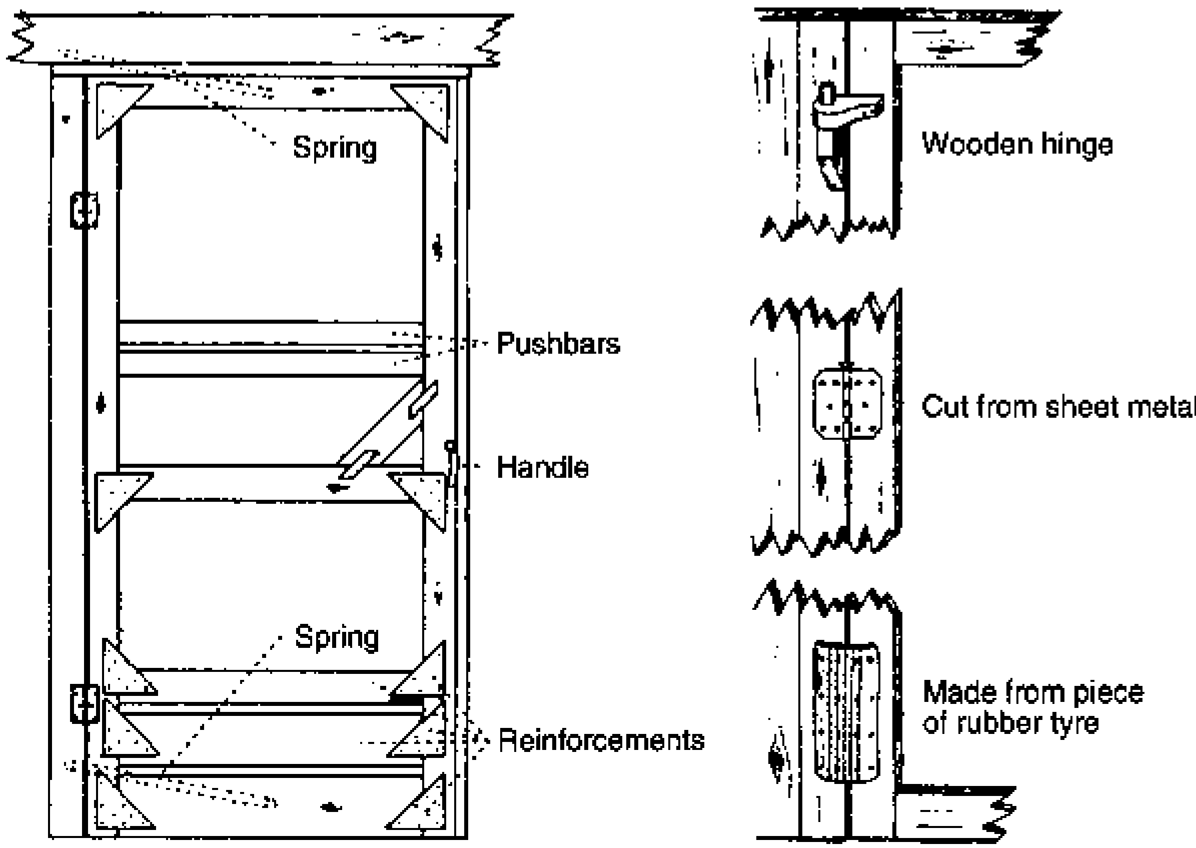


Fig. 1.82. Properly constructed screen door (left) and improvised hinges for a screen door or window (right) (© WHO).

Screening materials

Cotton netting: efficient but easily damaged; ventilation is reduced by up to 70%.

Metal screens: ventilation is reduced by 30 - 50%; rodents are prevented from entering. Many metals corrode rapidly in humid areas; stainless steel or copper screens avoid this problem but are expensive.

Plastic screens: cheap and easily fitted; ventilation is reduced by up to 35%. Nylon screening is not durable when exposed to direct sunlight; fibreglass coated in PVC is more durable.

Insecticide-treated screening and curtains

The treatment of screening with insecticide may provide a cheap and practical solution to some of the above problems. Treated screening or curtains provide a toxic barrier to mosquitos and other biting flies that try to enter houses (*115 - 119*). Because the treated surface of the screening irritates or kills mosquitos on contact they are not able to find openings in it. The disturbed behaviour of surviving mosquitos after such contact ends their attack. Mosquitos entering a house through unscreened openings may be killed later when attempting to leave through a treated screened opening.

In some houses, treated screening and curtains can be as effective as mosquito nets. In addition, they require considerably less netting and insecticide, and are thus cheaper, and unlike mosquito nets, once installed, little or no action is needed on a daily basis on the part of members of the household.

Problems with screening (Fig. 1.83)

Holes: mosquitos are persistent and often find openings.
Ventilation: fine-mesh screening obstructs flow of fresh air.
Windows and doors: movable screens are needed.
Eaves: often difficult to attach screening without leaving openings.

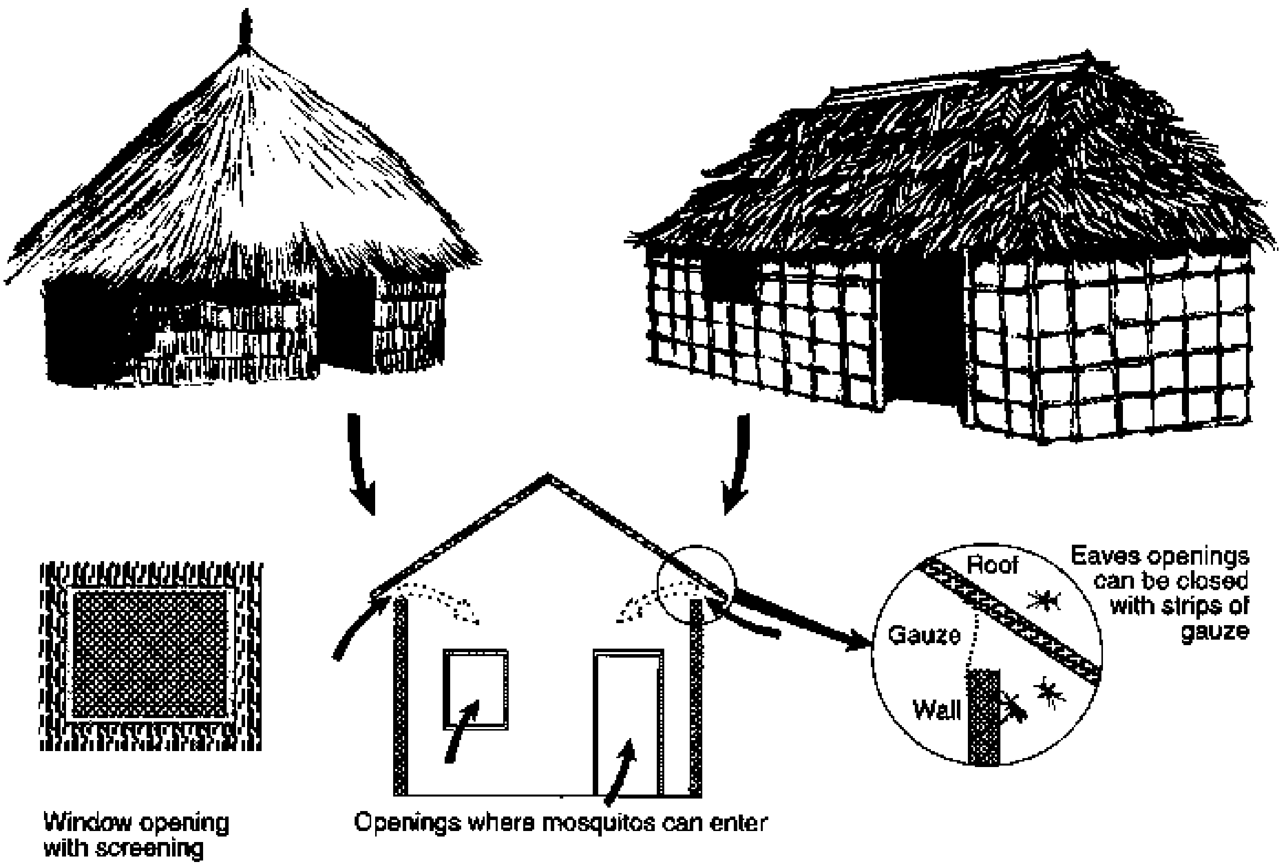


Fig. 1.83.(a) In these houses the eaves can be screened; window and door openings can be screened or closed.

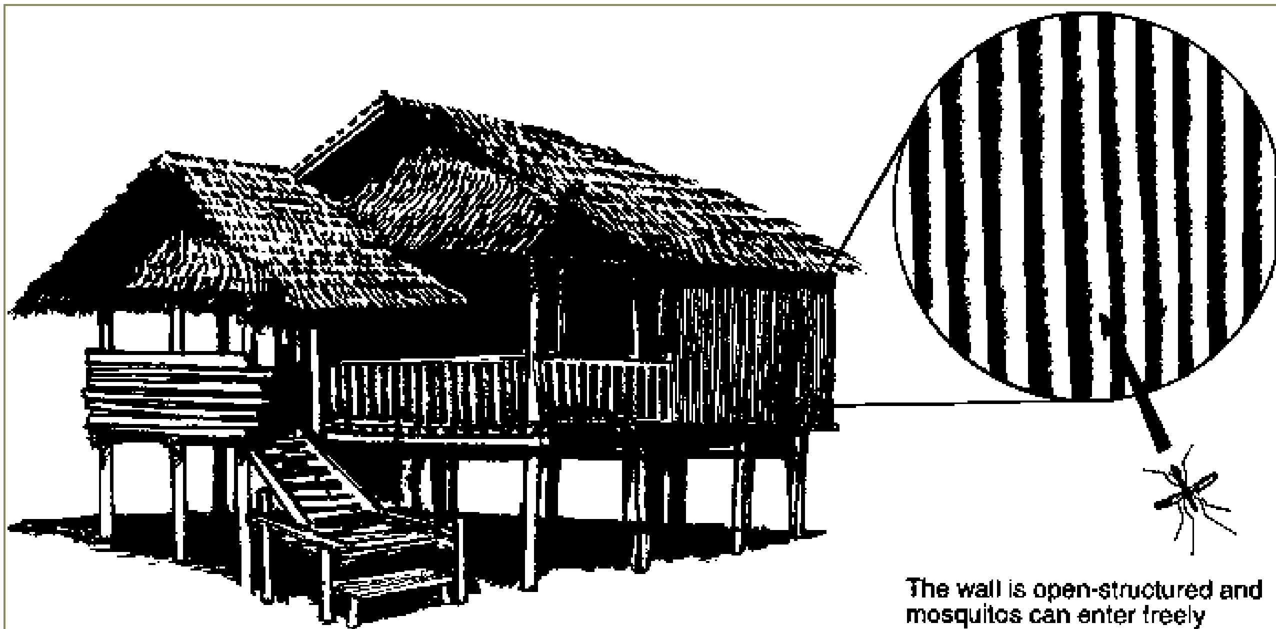


Fig. 1.83.(b) Screening of this house is impracticable. Insecticide vaporizers and mosquito nets are more appropriate.

Treatment method

The instructions given for the treatment of fabrics with insecticide (see p. 85) can be applied. Recommended dosages per square metre are 0.75 - 1.00 g of permethrin, 0.05g of cyfluthrin, or 0.025 - 0.035 g of deltamethrin or lambda-cyhalothrin.

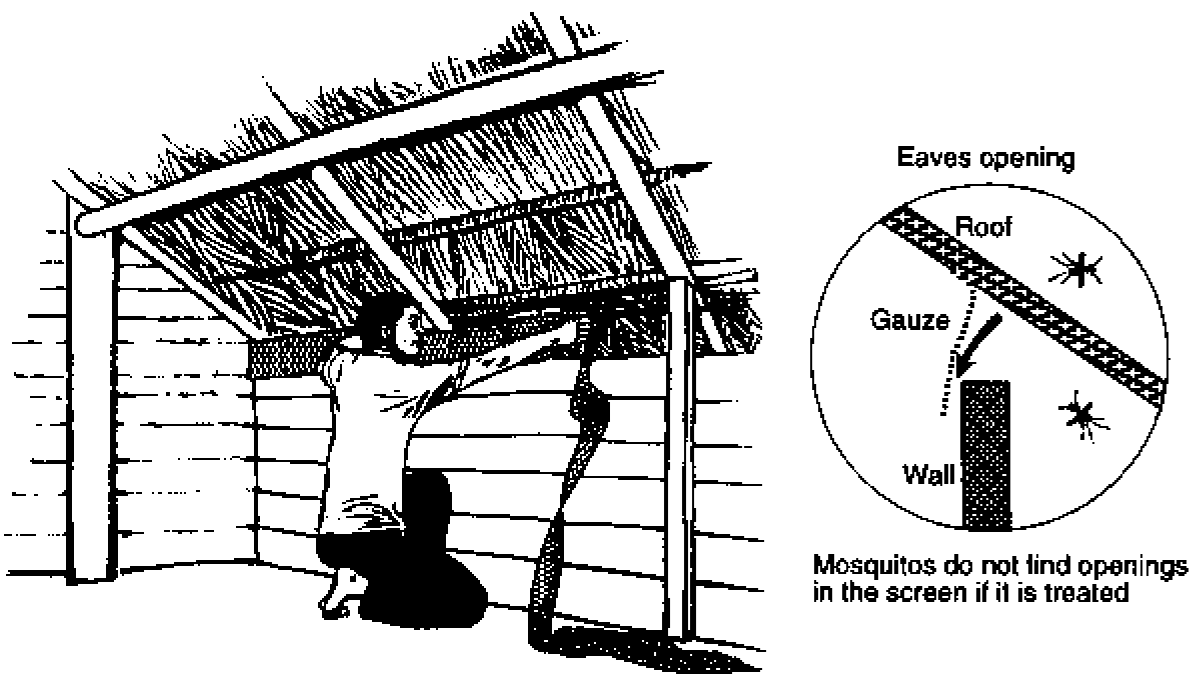


Fig. 1.84. Treated screening in the eaves need not fit exactly because mosquitos are unlikely to find openings (© WHO).

Practical advantages over untreated screening:

• Treated screening is easier to install. Because of the toxic effect, mosquitos are unable to search for holes or other small openings and so there is no need for the screening to fit perfectly (Fig. 1.84).

• A wider mesh size can be used (*102*, *103*) (see p. 84), allowing better ventilation, an important advantage in hot climates.

Alternative materials for screening

Instead of gauze it is also possible to use fibres and strips or loose hanging curtains for treatment (Fig. 1.85).

Materials that can be used:

- fibres obtained by unpicking polyethylene or jute sacks;
- string;
- bead curtains;
- plastic strips.

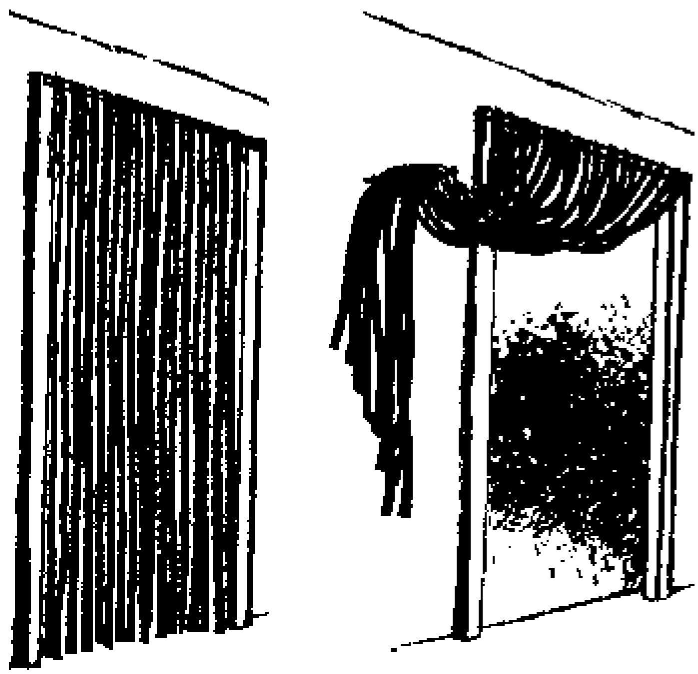


Fig. 1.85. Fibres or strips treated with insecticide can be used to protect doorways.

Protection measures for tents

Campers sleeping in tents are often attacked by biting insects. Many tents have screening of net or gauze but mosquitos may enter through small spaces when the screening is being opened or closed. Moreover, the mesh size of the screening is usually too large to stop biting midges that occur near swampy areas. To stop these insects the mesh size must be smaller than the usual 1.2 - 1.5 mm. However, a smaller mesh size could significantly reduce ventilation.

Possible solutions:

• Pressurized insecticide sprays and vaporizers could be used inside tents after closing. In small tents this could be unpleasant for the occupants because of the confined space. In bigger tents, mosquito coils offer protection throughout the night, but should be used with care because of the limited space and the flammability of tents and sleeping bags. If coils are used in a tent, they should be placed in coil holders (p. 65). Alternatively, the coil can be placed just outside the tent, in a coil holder to protect it from humidity and wind (Fig. 1.86).

• Screening can be treated with a repellent or a pyrethroid insecticide to deter flying insects such as midges which would otherwise pass through the mesh.

• A repellent for skin application (e.g. deet), sprayed on screens, may stop insects from passing through for several days. Treatment by spraying with or dipping in a long-lasting pyrethroid insecticide is preferable because it is cheaper and the effect lasts several months longer. Of these pyrethroids, only permethrin and flumethrin are available in spray cans (see p. 94). Alternatively, screening can be soaked in an emulsion of pyrethroid. Dosages are the same as for bednets (see Tables 1.3 and 1.4). Another method of application is to wet the screening with a sponge. The widely available pressurized spray cans containing knock-down insecticides are not suitable for treatment of screens because the insecticidal effect does not persist. Soaking the tent material itself with emulsifiable concentrate is not advisable (see box).

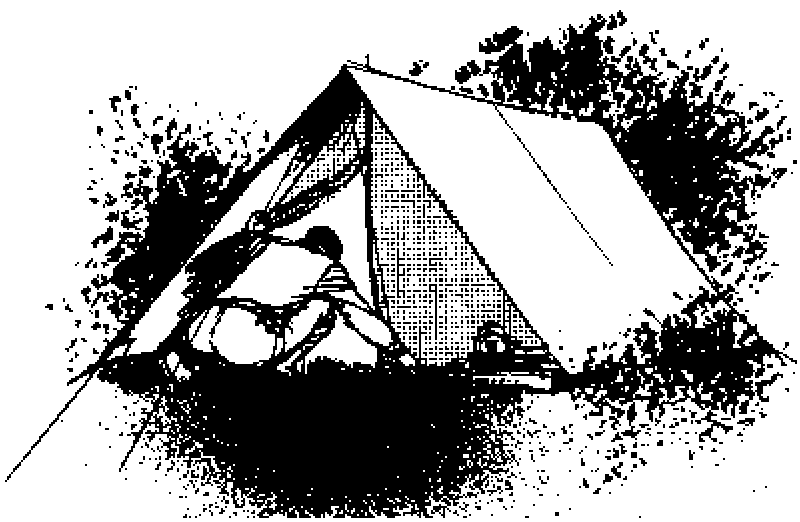


Fig. 1.86. Additional protection measures for campers: mosquito coils placed just outside the tent.

Spraying the interior surface of a tent

Nomadic people, refugees, soldiers and others living in tents in areas with endemic vector-borne diseases or insect nuisance may, under certain conditions, obtain protection by spraying the interior surfaces of their tents. As with the indoor spraying of houses, this kills indoor-resting mosquitos and sandflies and reduces other pests.

Because of the close contact with the tent material it is recommended to spray only with residual insecticides of low toxicity to humans, such as the pyrethroids. With permethrin, a dosage of 0.5-1.0 g/m^2 on the inside surface is recommended. On thick tenting material the spraying procedure is the same as for the spraying of house walls. Wettable powders are not suitable for this purpose, and emulsifiable concentrates should be used (*120*). However, emulsifiable concentrate formulations should not be used on waterproofed tent material, because they may affect the water-proofing. Oil-in-water emulsion formulations are suitable for such material.

Treated sheeting for temporary shelters

Temporary shelters are used by people who are on the move, among them gold-miners, hunters, loggers, rubber-tappers and semi-nomadic forest people. In addition, new settlers may live for some time in unfinished buildings. Such shelters offer little protection from biting insects, and consequently bednets and repellents are often used to reduce biting.

In addition to the use of treated mosquito nets, insecticide-treated sheeting (*121*) offers a more lasting solution. This material is attached to the poles of the shelter which support the roof, and can also be used to cover door and window openings (Fig. 1.87); it can be rolled up during the day. Some mosquitos that rest outside or inside on the sheeting are killed, and others are repelled after brief contact. Additional advantages offered by treated sheeting are those of privacy and protection from the wind. When the shelter is abandoned the sheeting can be removed and reused elsewhere.

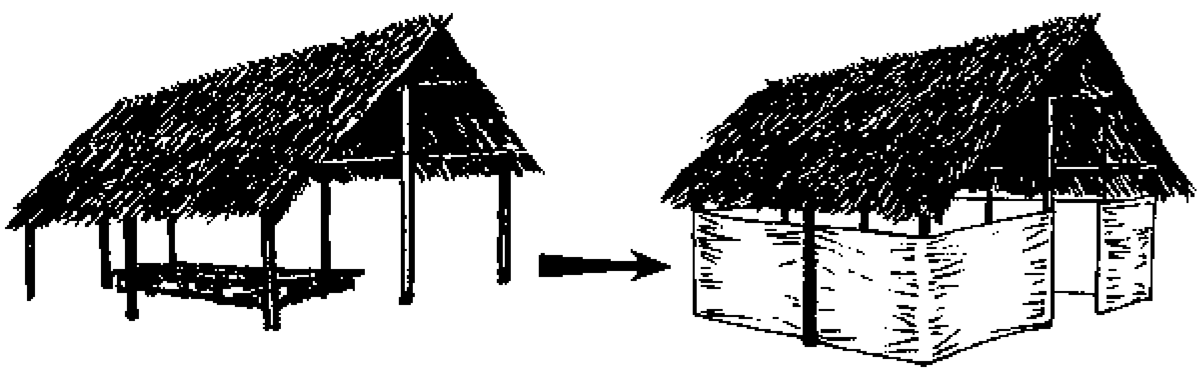


Fig. 1.87. Insecticide-treated sheeting of woven polypropylene can be attached to the poles of temporary houses.

The material must be strong, cheap and suitable for treatment. Woven polypropylene meets these requirements and is widely available. The pyrethroid insecticides appear to adhere well and show good resistance to being washed off by rain (G.B. White, personal communication).

Treatment method

The sheeting can be soaked or sprayed with pyrethroid insecticides, following the instructions given on p. 85. For speed and convenience, spraying may be preferred where spray pumps are available (see p. 93). Recommended dosages per square metre are 0.75 g of permethrin, 0.05 g of cyfluthrin, or 0.025 g of deltamethrin or lambdacyhalothrin.

Avoidance and diversion of biting Diptera

Avoidance

Personal protection is sometimes possible by avoiding places where mosquitos and biting flies are known to rest or breed, and by not visiting risky places during peak biting hours. For many species, these are the hours immediately after sunset and before sunrise.

House siting

Many mosquitos and biting flies prefer to fly against a slight wind, as it carries odours to them. Thus, when a new house or village is to be built or a tent or temporary structure erected, mosquitos can be avoided to some extent by choosing a site downwind of the nearest mosquito breeding sites (assuming that there is a prevailing wind direction). New settlements in forests could be surrounded by a forest-free belt between 1 and 2 km wide in order to gain protection from forest-dwelling mosquitos; a belt about 300 m wide is appropriate if protection is sought from phlebotomine sandflies. Sometimes it is possible to eliminate potential mosquito breeding or resting places outdoors by environmental measures such as drainage, levelling, and cutting bushes (see p. 114).

Many people prefer to place their houses close to rivers, creeks or ponds so as to be close to a supply of water. Depending on the breeding and resting habitats of the local vector species, this may increase the risk of being bitten. One solution could be to provide piped water or to collect rainwater in a mosquito-proof collection system.

Diversion to animals

In some areas, zooprophylaxis could be an effective way for communities and individuals to reduce their exposure to biting insects and the transmission of disease. Many mosquito and fly species prefer to feed on animals rather than on humans. Relocation or the introduction of cattle or other domestic animals may divert many mosquitos from humans to animals. Differences between villages in the same area in the mosquito biting rates or in the numbers of malaria cases can sometimes be explained by the presence or absence of domestic animals (*122 - 124*). Cattle placed between settlements and mosquito breeding and daytime resting sites, for instance on the outskirts of villages, attract mosquitos and thus provide some protection for humans. In Japan, the siting of animal shelters far away from rice fields proved effective against the *Culex* vector of Japanese encephalitis (*14*).

However, the local situation needs to be studied by experts before this method can be recommended. Pigs, for example, may serve as a reservoir of Japanese encephalitis in rice-growing areas in parts of south-east Asia. If they are kept near human habitations in an attempt to attract mosquitos away from people, some mosquitos may carry the disease from animals to humans, making the situation worse rather than better.

In practice, there are few known instances of people using this method successfully to reduce biting nuisance or disease transmission. However, there are examples of people suffering from an increase in bites and disease transmission because cattle and other animals were removed and bloodsucking insects were left with only people to feed on. This has happened where draught oxen have been replaced by tractors, where cattle farming has been abandoned (*125*) and in settlements in forest areas where wild animals have disappeared as a result of hunting. Malaria epidemics in India have been explained by a decrease in the number of cattle linked to severe drought in one year followed by heavy rains in the next, creating abundant mosquito breeding sites (*126*).

The presence or absence of animals in a village may have an impact on the effectiveness of vector control measures. For example, domestic animals may enhance the effectiveness of mosquito nets by providing easily available alternative blood-meals to mosquitos that have failed to feed on people sleeping under bed-nets. Without attractive animals in a village to feed on, hungry mosquitos are likely to persist until they manage to feed on a person not protected by a mosquito net (see box, p. 82).

Insecticide spraying

Insecticide spraying of walls

Mosquitos and biting flies seek shaded undisturbed resting sites for part of their life. In drier regions, houses are an important resting place for mosquitos and phlebotomine sandflies. In humid forested areas the insects are less dependent on houses and often rest in vegetation outdoors. However, even species that usually rest outdoors may enter houses to feed and may then spend some time resting indoors before and after feeding.

When mosquitos and other insects rest in houses it is possible to kill them by spraying the walls with a residual

(long-lasting) insecticide. Mosquitos resting on sprayed walls come into contact with insecticide through their feet and are killed. Some insecticides irritate mosquitos and cause them to leave houses. In dry or windy areas, this may also result in death due to lack of suitable outdoor resting places. Wall-spraying may not prevent biting. Hungry mosquitos entering a house may bite first and then be killed when resting on a treated wall.

As most anopheline vectors of malaria enter houses to bite and rest, malaria control programmes have focused primarily on the indoor application of residual insecticides to the walls and ceilings of houses. House-spraying is still an important malaria control method in some tropical countries while in others its importance is diminishing because of various problems that have arisen. Methods that are less costly and easier to organize, such as community use of impregnated bednets, and that produce long-lasting improvement, such as elimination of breeding sites, are now being increasingly considered.

Indoor residual spraying is generally not very effective against *Aedes aegypti*, the vector of dengue, or against *Culex quinquefasciatus*, the vector of lymphatic filariasis, at least partly because of their habit of resting on unsprayed objects, such as clothes, curtains and other hanging fabrics rather than on walls and ceilings (*127*). Moreover, *Culex quinquefasciatus* is resistant to DDT and other chlorinated hydrocarbon insecticides. Other insecticides, with the exception of the residual pyrethroids, would be too expensive for sustained control over many years. A practical problem in urban areas is the large number of rooms that would have to be sprayed.

The spraying of houses and animal shelters in rural areas to control the *Culex* vectors of Japanese encephalitis is also generally ineffective because of the outdoor biting and resting habits of the vector species (*5*).

Sandflies that rest indoors can be effectively controlled by spraying the inside surfaces of walls and the interiors and exteriors of doorways, windows and other openings with residual insecticides. The insecticides, dosages and application techniques are similar to those used against anopheline mosquitos for malaria control. Only in a few areas have insecticides been sprayed against leishmaniasis alone. In most cases the control of malaria mosquitos has been the main priority, that of sandflies being coincidental.

Spraying requirements

Before spraying is undertaken, detailed studies should be conducted to obtain data on the localities where disease transmission occurs, the season of transmission, the vector, its resting and biting behaviour, and its susceptibility to insecticides.

Proper insecticide spraying also requires trained personnel; these may be professionals employed by a government programme or community members employed by a local health organization to carry out spraying duties seasonally. Spraying equipment needs maintenance, and spare parts must be available.

How to spray

The insecticide is normally sprayed on to a surface with a hand-compression sprayer. For a discussion of suitable insecticide formulations, spray pumps, spraying techniques and the maintenance of equipment, see Chapter 9. The insecticide should be selected for its effectiveness against the target mosquito species, its price and its availability. A decision should be taken only after consulting the health authorities.

Where to spray

The entire inner surfaces of roofs and walls and the lower surfaces of large items of furniture are usually sprayed (Fig. 1.88). In some areas, vector species rest only on the lower wall surfaces, for example below 1.5 m, so substantial savings can be made by spraying wall surfaces only up to that height. Conversely, some mosquito species prefer to rest in the upper parts of houses, close to the roof.

When to spray

In areas where mosquitos transmit malaria or other diseases seasonally, insecticides should be applied just prior to the onset of the period of transmission. This is particularly important when short-lasting insecticides are used which offer protection only for a few months. Large programmes may have timing difficulties because of the need to spread the spraying operations over the year; priority should be given to optimal timing of spraying in localities known to have most cases of malaria.

Special precautions to be taken before a house is sprayed

Furniture and food must be removed from the house or placed in the centre of a room and covered with a plastic sheet to stop insecticide particles settling on them (Fig. 1.89). The person carrying out the spraying must wear a hat and clothing that covers as much of the body as possible, including arms and legs. For indoor spraying it is recommended that the nose and mouth be covered with a simple disposable or washable mask (see Chapter 10).

Fig. 1.88. Wall and roof surfaces can be sprayed with a residual insecticide against indoor-resting mosquitos.

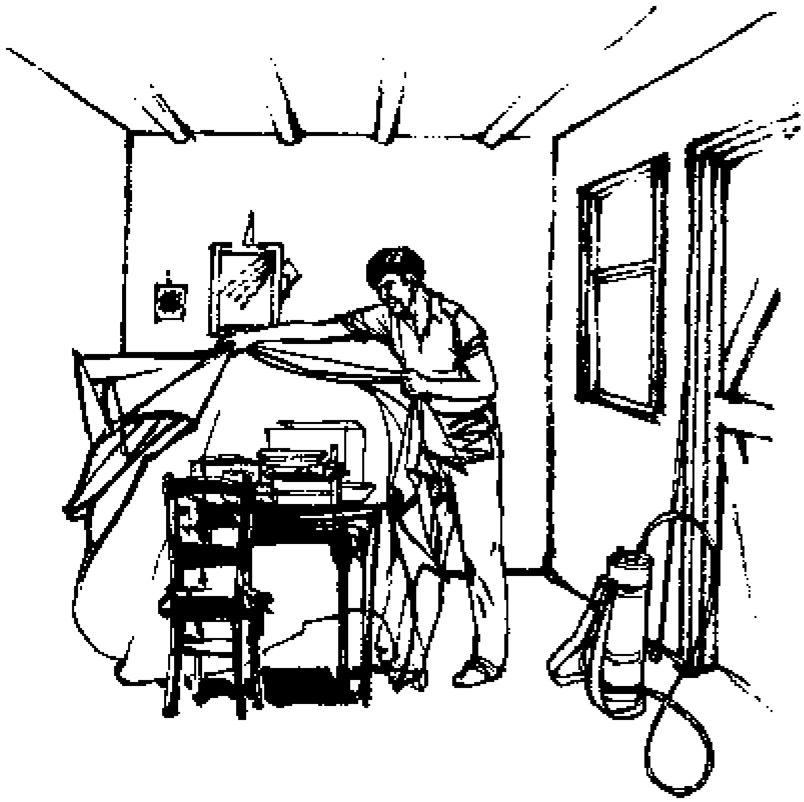


Fig. 1.89. Furniture and food must be removed or covered with a plastic sheet before a house is sprayed.

Some problems related to house-spraying

- In some areas vector insects may be resistant to the commonly used insecticides.

- The spraying of walls often leaves a visible deposit of insecticide, especially when a wettable powder suspension is used. The use of the emulsifiable concentrate formulation of the same insecticide or a more potent compound requiring a lower dosage (e.g., one of the pyrethroid insecticides) may partly solve this problem; however, some of the alternative formulations and insecticides may be too costly for use on a large scale.

- Some people may object to wall-spraying on religious grounds.

- The washing or replastering of walls, as may be done for religious or cultural reasons, reduces or eliminates the efficacy of insecticides.

- The community may be reluctant to allow strangers into their houses, for fear that they will interfere with women or steal.

- Some domestic pests, such as bedbugs, have become resistant to DDT and certain other insecticides. As a result, house-spraying no longer offers the incidental benefit of their control; furthermore, it is widely believed that spraying makes these pests more aggressive.

Alternative methods for applying insecticides to walls

Insecticidal paint can be applied to suitable surfaces, such as timber or plaster (Fig. 1.90). This method requires more time but can be done without spray pumps. If a wall surface is to be painted anyway, the only extra cost is that of the insecticidal ingredient.

Insecticidal paints are commercially available but can also be made by mixing insecticide with ordinary paint. The following factors have to be taken into account:

- the paint must have a neutral pH because most insecticides degrade rapidly when mixed with an alkaline paint emulsion;

- the insecticide must have a high vapour pressure to ensure movement of the insecticide particles to the surface of the paint (e.g., propoxur, pirimiphos methyl, fenitrothion).

Where it is common practice to replaster interior wall surfaces of mud or cement, attempts have been made to mix insecticide with the plaster before its application. This is not recommended because most of the insecticide is wasted, being unavailable for contact with insects at the surface.

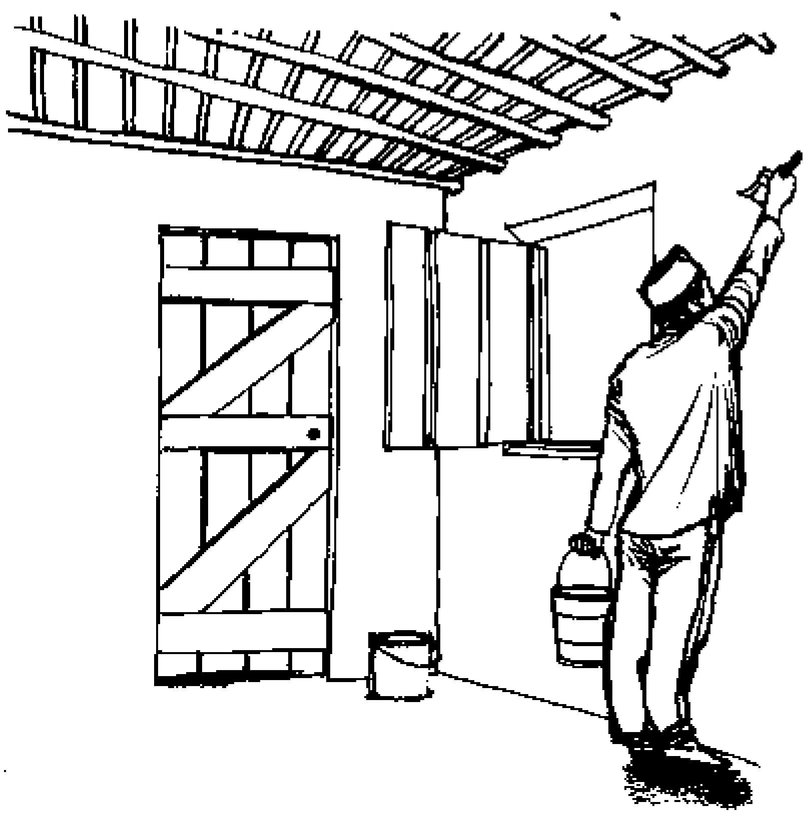


Fig. 1.90. Insecticidal paint can be applied with a brush.

Space-spraying with insecticides

Insecticidal aerosols are sometimes used for the killing of flying and resting insects in situations where immediate results are needed, for example during outbreaks of disease or when high densities of nuisance insects are a public health problem (Fig. 1.91). Because the insecticidal action does not last long it is usually necessary to repeat the procedure several times. Space sprays are usually applied in and around houses in cities or villages and sometimes on outdoor resting places in dense vegetation or salt marshes. Special equipment is needed, such as motorized knapsack mist-blowers or shoulder-carried thermal foggers. Vehicle- or aircraft-mounted aerosol generators are also available. Space-spraying involves the use of thermal or cold fogs and ultra-low-volume sprays (*128*, *129*).

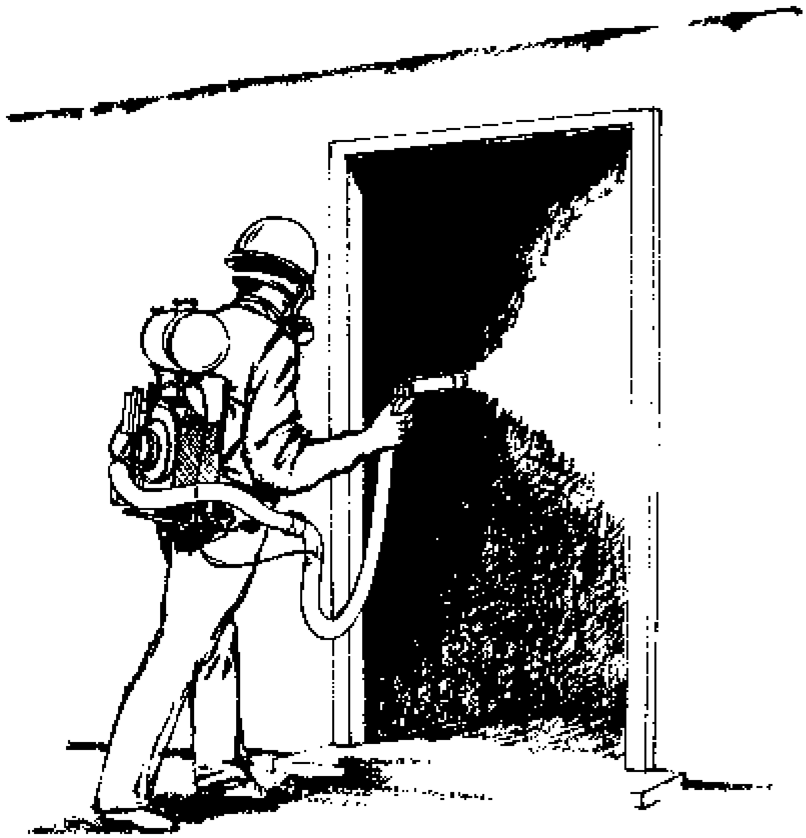


Fig. 1.91. During epidemics and when the density of nuisance mosquitos reaches an unacceptable level, space-spraying can be carried out for immediate short-term results.

Acceptance of space-spraying by communities

In many communities there is growing concern over the use of insecticides and their impact on health and the environment. The extent to which this affects public cooperation varies widely between countries and localities. However, with appropriate educational messages, especially during vector-borne disease outbreaks or when the nuisance problem is severe, compliance with official requests to open doors and windows to allow better penetration into houses of aerosols and fogs is likely to be increased. The spraying of insecticides from motorized truck-mounted machines is a high-profile activity, often regarded as a means by which political leaders can be seen to be taking action to address the problems of nuisance or disease transmission.

Space-spraying has a number of advantages and disadvantages in comparison with residual wall-spraying:

Advantages:

- it has an immediate effect on adult populations of insects and is therefore suitable for the control of disease outbreaks;

- for a single application, it is less labour-intensive and large areas can be treated fairly quickly;

- less insecticide is required for one application in urban areas;

- it kills mosquitos that do not rest in houses.

Disadvantages:

- it has a high recurrent cost: the effect of the spray does not last and spraying may have to be repeated;

- the cost of equipment is high, as are operational and maintenance costs;

- there is a need for specially trained staff for maintenance and repair;

- its high cost makes it unsuitable for multiple applications in rural areas;

- it may cause pollution and contamination of non-target areas and organisms;

- there are problems with acceptability among inhabitants of some areas because of the odour and the belief that the spraying is unhealthy.

Prevention of breeding

This section provides practical information on methods for preventing breeding by mosquitos. The other groups of biting Diptera are not included here because the available methods are generally not suitable for use by non-professionals.

Mosquito species differ in their preferences for breeding habitats. Thus, some species breed in clean water containers in and near houses, whereas others prefer polluted water in sanitation systems, or man-made and natural habitats in rural areas. In order to gain knowledge of the exact type and location of the breeding habitats of a target species, careful study by an expert is generally required; once the breeding sites are known, appropriate control measures may be simple and inexpensive.

In the domestic environment, such studies are less important: most breeding sites in and near houses are easy to identify and simple methods are available to eliminate them. Community members can and should take action against any breeding by mosquitos observed on their premises, irrespective of the importance of the species as a nuisance or vector of disease.

Larval control may be the only effective approach when mosquitos bite outdoors and do not enter houses to feed or rest, or when the mosquitos are not susceptible to the available insecticides. An important advantage of larval control is that some of the measures provide permanent protection. Permanent control of mosquitos can be obtained by altering or eliminating the breeding places; this is called source reduction. Such measures include covering or screening water containers, draining ponds and marshes, and filling in ditches, pools, etc. Semipermanent measures that have to be repeated include cleaning up refuse and containers serving as breeding sites, clearing vegetation from the shores of ponds and creeks, changing water levels in lakes and reservoirs, flushing streams and repairing drains.

Many breeding sites in both urban and rural areas are man-made and their creation should be avoided as much as possible. Examples of such breeding places are: used tins and bottles, leaks from taps and water pipes, badly designed drainage and sewage disposal systems, faulty irrigation systems, borrow-pits and reservoirs. Good planning, design and maintenance can prevent much mosquito breeding.

Larval control is also possible without changing breeding sites. Fish that eat mosquito larvae can be released into breeding sites, and substances that kill the larvae, such as chemicals, bacterial larvicides, oils and polystyrene beads can be applied to the water surface.

The control of larvae does not have an immediate effect on the numbers of biting mosquitos, and it may be several days or weeks before a reduction in their numbers can be achieved. Larval control provides protection for a community or a few neighbouring households rather than strictly personal protection: all people living close to the former mosquito breeding places will benefit. On the other hand, mosquitos will continue to fly in and bite if breeding continues nearby.

Methods to control larvae include the following:

- eliminating or changing the breeding place to make it unsuitable for development of larvae;
- making the breeding place inaccessible to adult mosquitos;
- releasing fish or other predators that feed on larvae;
- applying larvicides.

How appropriate is larval control?

The control of breeding places must be carried out around human settlements in an area with a radius greater than the flight range of the target mosquito species. For many species this is about 1.5 - 2 km. Control measures that are not permanently effective have to be maintained throughout the period when the mosquito acts as a disease vector. The effort and expense needed to obtain effective control in such a large area for the necessary time vary little with the size of the settlement. Larval control is therefore more costly per person in sparsely populated areas than in densely populated ones. In contrast, the cost per person of measures to control adult mosquitos, such as the use of insecticide-treated bednets or indoor residual spraying, is similar in rural and urban areas. In urban areas, larval control is often more cost-effective than the control of adult mosquitos.

In places with intense transmission of malaria, almost all anopheline breeding sites need to be eliminated in order to achieve a reduction in the prevalence of malaria. Even a much reduced population density of anopheline mosquitos may be able to maintain a high prevalence of the disease.

Effective larval control is most feasible where breeding places are:

- limited in number;
- easily recognizable;
- easily accessible.

It is also preferred where:

- the mosquito breeds only during a short period;
- measures to control adult mosquitos are ineffective or culturally unacceptable;

- permanent source reduction measures are more cost-effective than repetitive control measures.

Source reduction

The term source reduction refers to any measure that prevents the breeding of mosquitos or eliminates their breeding sites. If such measures are long-lasting or permanent changes in land, water or vegetation, they are often referred to as environmental modification. When such measures have a temporary effect and need to be repeated, they are known as environmental manipulation. The drainage of swampy areas, land reclamation and other permanent methods were already being implemented early in the twentieth century. In many areas they have played an important role in the elimination or reduction of a number of vector-borne diseases.

Environmental modification

Removal or destruction of breeding sites

Small containers, such as used cans, bottles, tyres and coconut husks used as breeding sites can be removed or destroyed. This method is commonly used to control the breeding of *Aedes aegypti* and *A. albopictus*.

Filling

The filling of mosquito breeding sites with soil, stones, rubble, ash or rubbish is the most permanent control measure available. It is most suitable for reducing breeding in small depressions, water holes, borrow-pits, abandoned ditches or pools, which do not require much filling material. On a small scale, no special expertise is needed and communities can carry out the work with shovels, picks, wheelbarrows, carts and other simple equipment. For larger landfills, tractors or other motorized equipment may be preferable. The filling material should be obtained without creating new breeding sites. Waste materials can be used for most filling.

If refuse is used it should be compacted and covered with earth to prevent breeding by flies. All fills should be topped with clean earth and graded to make the areas attractive and suitable for use as building sites, playgrounds, etc. It may be possible to collaborate with industrial or agricultural firms or public works departments, so that trucks transporting waste materials are diverted at no extra cost to places that need to be filled.

Very large areas can sometimes be filled at little cost by making use of the spoil from mining, harbour dredging, building demolition and other operations.

Drainage

The drainage of water can be accomplished by constructing open ditches and dykes with tidal gates, subsoil drainage and pumping. Proper drainage reduces mosquito breeding; however, the drainage systems used in agriculture or for the transportation of sewage and rainwater in cities are often an important source of breeding because of poor design and maintenance. Leakages, obstructions, and small pools or puddles of residual water in drainage ditches often afford suitable breeding sites for mosquitos. The planning and construction of drainage systems are complicated and require the expertise of engineers. However, some small-scale drainage works intended to control mosquitos can be carried out by less experienced people using simple equipment (*130*).

Open ditches

Open earth drains are the simplest to construct. They are used to prevent the accumulation of excess rainwater in depressions in the ground and to dry out marshy areas, borrow-pits, ground pools and other accumulations of surface water.

Layout The ditches carry the water away to an appropriate, lower-lying outlet, such as a river, creek, pond, soakaway pit or main drainage ditch. They should follow the natural flow of water along the surface. To prevent erosion of the lining of the ditch they should be as straight and short as possible. Sharp bends should be avoided wherever possible (Fig. 1.92).

A main ditch may have several lateral or secondary ditches to collect water that does not readily drain into the main ditch. However, the number of such lateral ditches should be kept to a minimum to reduce maintenance.

Where lateral ditches enter the main ditch they should be brought together at an angle of about 30 degrees with the direction of the flow. If the angle is larger, the flow of water from the lateral ditch may erode the opposite bank of the main ditch. The lateral ditch should preferably enter the main ditch slightly above the normal water level in the main ditch.

Gradient To give the water enough velocity the gradient should be between 1 and 5 cm per 10 m. If the gradient and velocity are too high, this will cause erosion of the bottom and sides of the ditch.

Shape (*cross-section*) The optimum shape depends on the soil texture, among other factors. In stiff clay and other types of stable soil the sides may be vertical, but in sandy soils the slope may need to be 4:1, that is 40 cm horizontally for every 10 cm vertically. In most soils the slope should be about 1:1 to 2:1.

Depth This depends on the elevation of the area to be drained and on the outfall. The bottom of the ditch must be 15 cm lower than the bottom of the pool, marsh or other area to be drained.

Excavated soil or spoil Excavation of the ditch should start at the outfall end and proceed up to the area to be drained. The excavated soil is used to fill in depressions. If left alongside the ditch it should be spread or piled up evenly on each side at some distance from the edge so that it cannot be washed into the drain. A spoil bank should be perforated at frequent intervals to permit drainage into the ditch (Fig. 1.93).

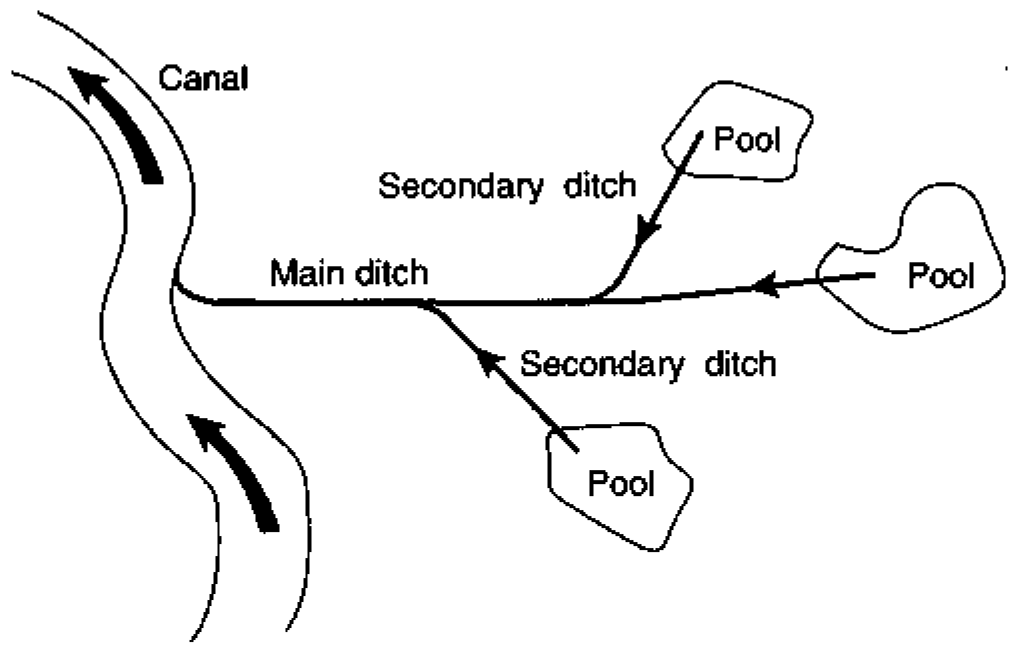


Fig. 1.92.(a) Correct drainage of pools. (*131*).

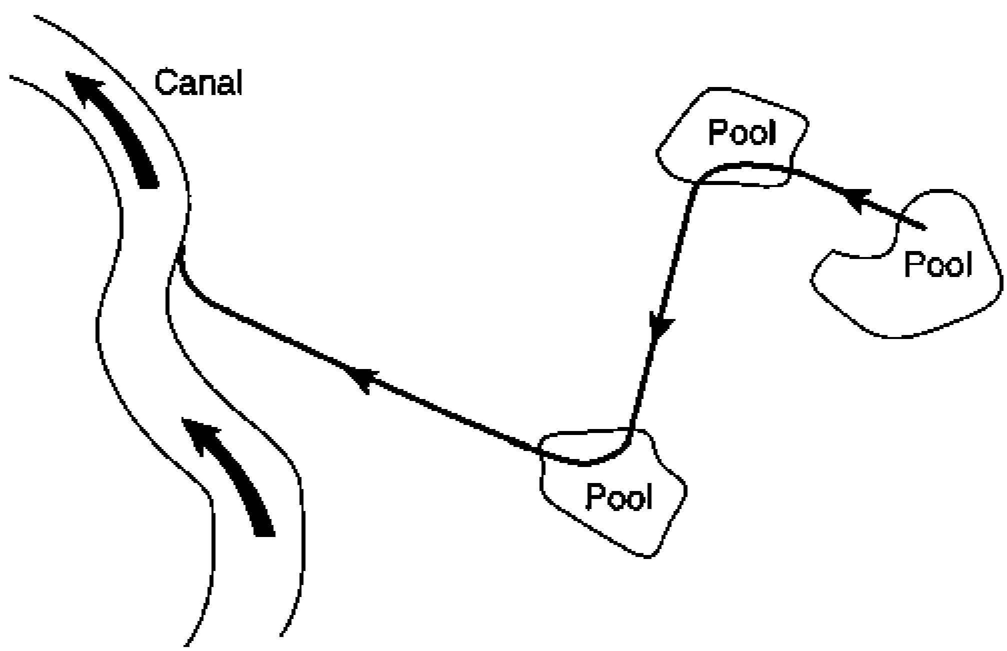


Fig. 1.92.(b) Incorrect drainage of pools. (*131*).

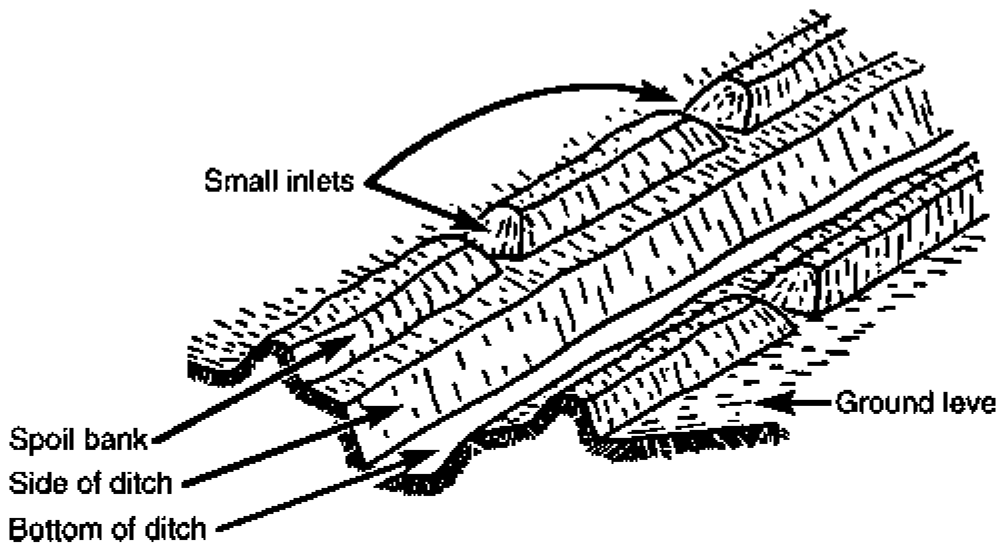


Fig. 1.93. Location of a spoil bank at some distance from the edge of a ditch. The spoil bank is perforated to permit drainage into the ditch (*132*).

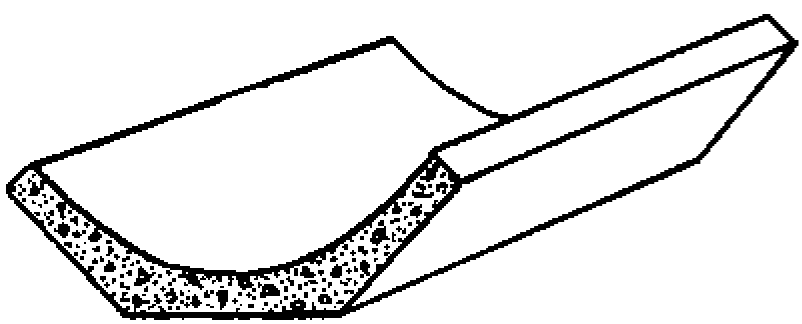


Fig. 1.94. A precast concrete slab used for lining ditches (*131*).

Lining of banks Where necessary the banks can be stabilized with masonry, bricks, poles or turf. The banks usually need to be stabilized in areas where water is turbulent, for instance near bends or where a lateral ditch enters a main ditch. By lining earth drains their performance can be improved and the cost of maintenance can be reduced. The drains last longer, are more easily cleaned, require less inspection and may ultimately be less costly than open earth drains. Open earth drains are of no use in areas with very heavy rainfall.

A drain may be roughly lined with flat stones and the spaces filled in with small stones and sealed with cement. Alternatively, a layer of concrete, 4 - 5 cm thick and reinforced with wire mesh may be used. Connecting precast slabs are also commonly used. They are usually made of concrete in sections of 60 - 70 cm with a rounded bottom and a joint to facilitate laying them in a prepared ditch (Fig. 1.94). In larger ditches, side-slabs of turf or concrete may be laid above the slabs (Fig. 1.95). In small ditches it may not be necessary to line the entire drain; lining the bottom and the sides up to 8 cm above the normal water line is usually sufficient. The banks should be kept clear of vegetation.

Culverts In places where the drain has to pass beneath a road or embankment by means of a culvert or pipe the gradient should be increased to prevent the accumulation of debris and silt (Fig. 1.96). At the entrance, a screen of vertical rods may be provided to prevent debris from entering. Culverts can be made of wood, concrete, corrugated iron, or plastic. The last two materials are preferable since they withstand stresses better than the others. Pipes can be made cheaply from used oil drums by cutting out the bottoms.

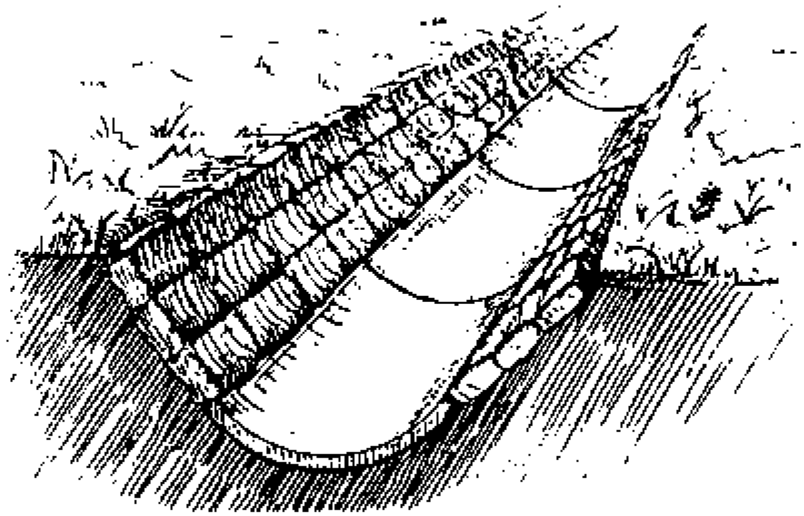


Fig. 1.95. A ditch lined with concrete and turf (*131*).

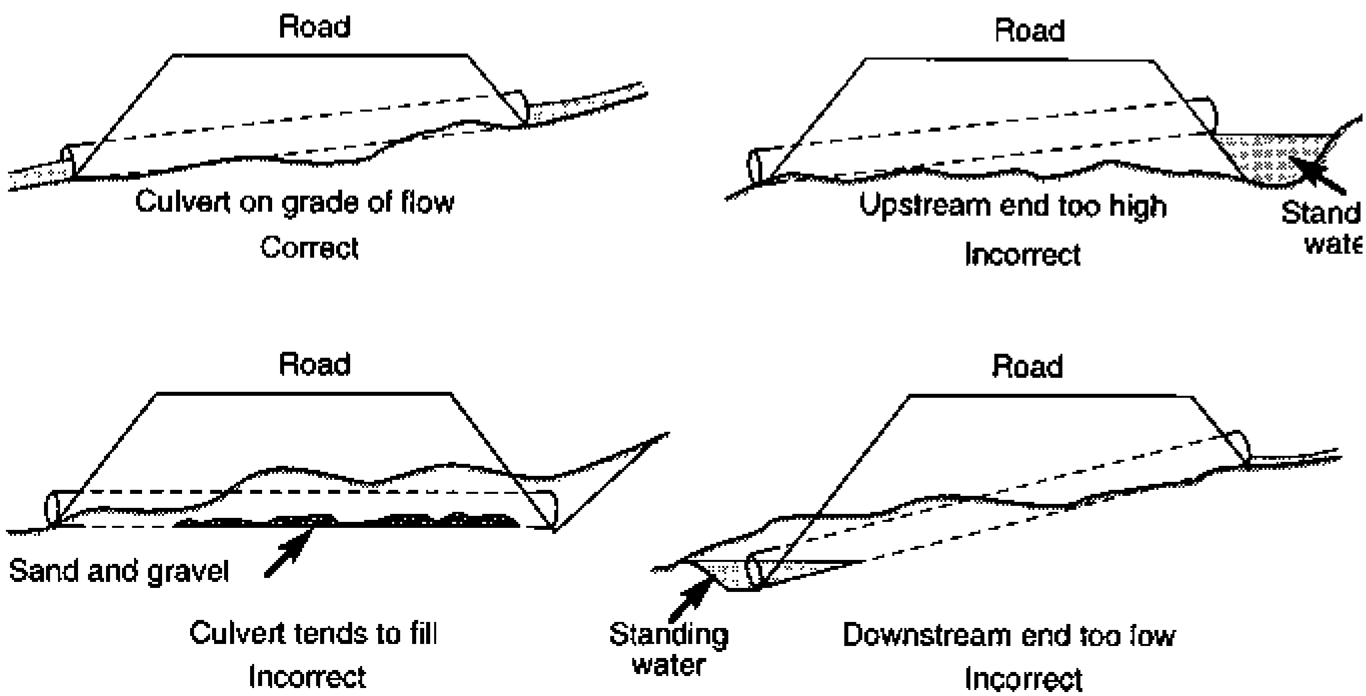


Fig. 1.96. Correct and incorrect installation of culverts (adapted from *131*).

Subsoil drainage

Subsoil drainage is more expensive than open drainage and therefore of limited value in the control of mosquitos. It is used where the ground surface has to remain unbroken by ditches to allow free movement and use of the land, and where the carth is so unstable that open ditches cannot be maintained. The advantage of this system is that the drains do not become choked with vegetation or blocked by refuse. It usually requires little inspection and additional larval control measures, such as the spraying of larvicides or oils, are unnecessary.

Subsurface drains are often used in irrigated areas for draining fields and improving agricultural production. They have been constructed specifically for mosquito control in Malaysia with the intention of lowering the groundwater level so that pools of surface water are more readily absorbed. They are also used to intercept seepage water from hills and to deal with hill streams in ravines.

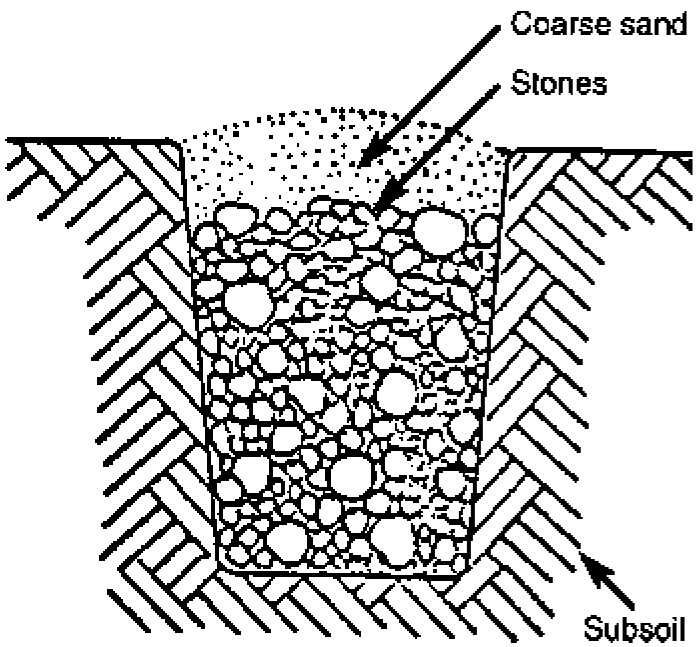


Fig. 1.97. Cross-section of a simple subsoil drain: a ditch filled with a layer of stones covered with coarse sand (*130*).

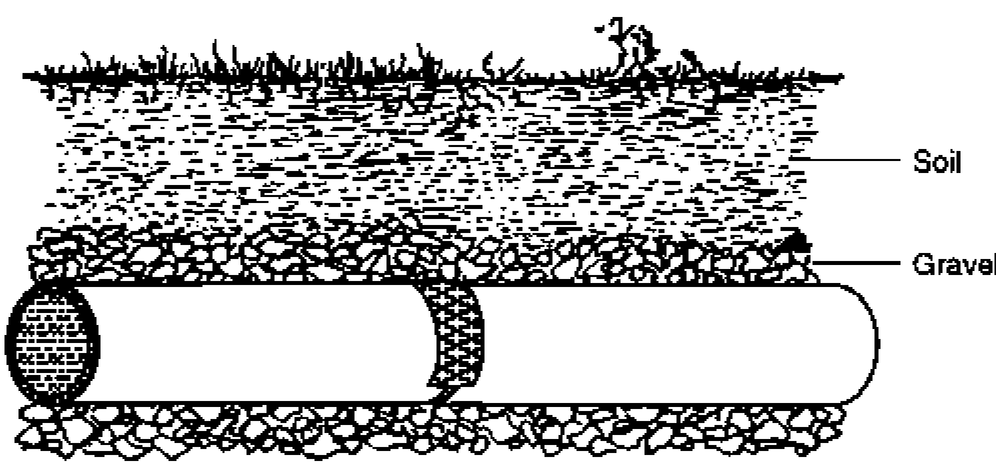


Fig. 1.98. A subsoil drain made of unsealed tile pipes. The joints are covered with a collar of clay, roofing paper or other resistant material (*133*).

The simplest such drain is made by filling a deep ditch with large stones that offer little resistance to the flow of water. Cover the stones with leaves, pine needles, palm leaves or coarse sand to serve as a filter (Fig. 1.97). This prevents silt and clay from clogging the lower section of the drain. Other simple filling materials that can be used at the bottom of the drain are thick wooden or bamboo poles and inverted halves of coconut husks. This layer can be covered with coarse grass or litter and topped with soil.

An effective type of drain consists of ceramic tile pipes. The pipes are laid end to end at the bottom of a narrow ditch about 0.5 - 2 metres below ground level. The joints are left unsealed so that water can enter. On the upper half the joints are covered with garbage, leaves, strips of roofing paper, plastic or other resistant materials to reduce silting (Fig. 1.98). The pipes should be laid in an absolutely straight line with a gradient of between 1:200 and 1:400, depending on the quantity of water to be transported. Greasy water and domestic waste must not be allowed to discharge into any part of the system. Where pipes come close to the surface they may have to be protected from being crushed by vehicles by the construction of small bridges.

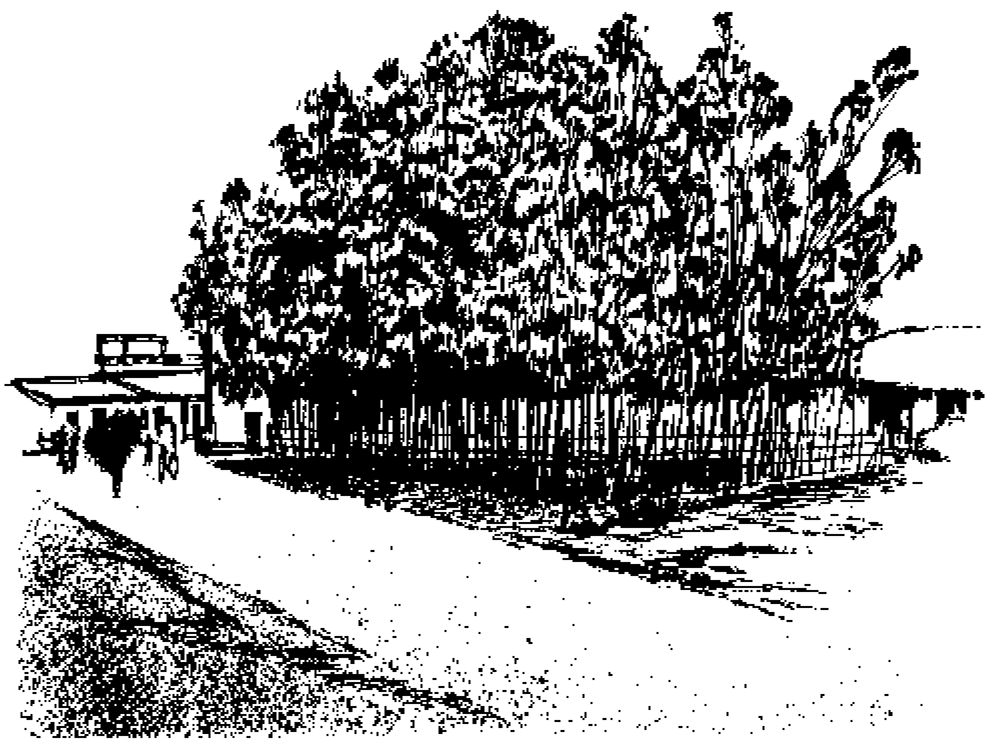


Fig. 1.99. Fast-growing eucalyptus trees dry low-lying marshy areas and prevent breeding by mosquitos.

Eucalyptus trees

Eucalyptus trees can be used for drying marshy areas and other plots of land with a high water table (Fig. 1.99). Species that grow rapidly and use a lot of water are particularly suitable. The trees dry the land by allowing water to evaporate through their leaves. For optimum evaporation they should be planted with adequate spaces between them. An additional advantage of the trees is their commercial value.

Closing, screening or covering breeding sites

Potential breeding sites in relatively small enclosed habitats, such as drinking-water storage containers and wells, should be made inaccessible to adult mosquitos. Removable covers, such as mosquito-proof lids or wire mesh screening, can be fitted in some cases (see p. 144). Wells can be made mosquito-proof by closing them with cement slabs and installing hand pumps. Latrines can be made insect-proof by improving their design (p. 149). A less conventional approach is to cover the water surface completely with a material that is impenetrable to mosquitos. Examples are expanded polystyrene beads and fast-growing plants that float on the surface, such as the aquatic fern *Azolla* (p. 163).

Expanded polystyrene beads

Expanded polystyrene beads can be spread on water to form a floating layer (Fig. 1.100). A layer 1 - 2 cm thick is sufficient to prevent mosquito breeding if it covers the surface completely. The mosquito larvae die because they cannot reach the water surface to breathe. The beads do not decay and remain floating for years. Because they are easily blown or washed away, the beads can only be used in sites where the water remains confined between surrounding walls. Polystyrene beads are not toxic to humans, animals or fish and are safe for use in drinking-water (*134 - 140*).

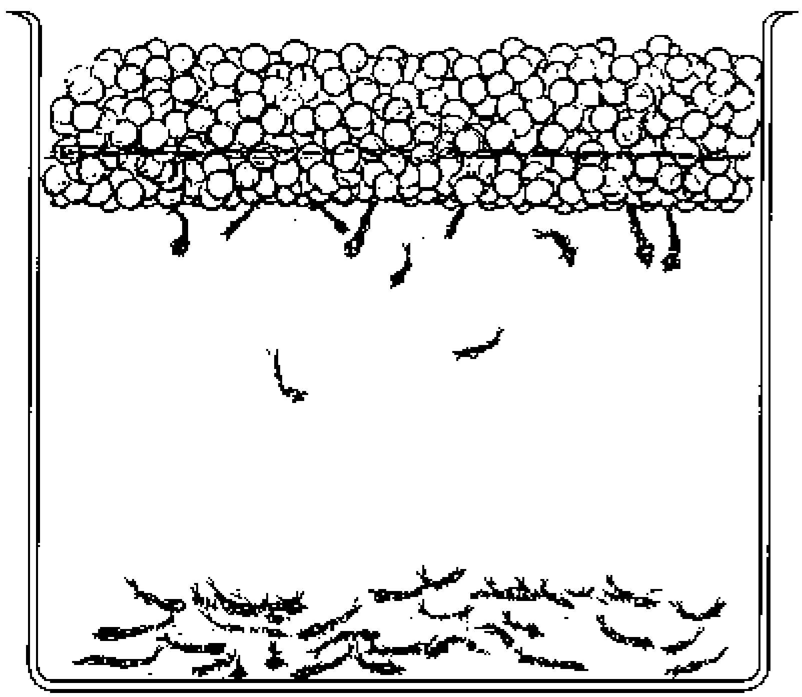


Fig. 1.100. A layer of polystyrene beads prevents mosquito larvae from reaching the water surface to breathe.

Production and application Small balls (or beads) of expanded polystyrene pressed together in blocks are often used as packing material. Small quantities of beads can be obtained by breaking up and crumbling such blocks. Larger quantities can be obtained from the petrochemical industry, which produces unexpanded polystyrene beads with pentane in solid solution in each bead. The beads are expanded by heating them to 100 °C in steam or boiling water. The plastic softens and the pentane, which becomes gaseous, expands the beads to 30 times their initial volume. The beads can be expanded in a suitably equipped factory and then transported in sacks or drums to the sites of application.

Transport of the beads is easier if they are in unexpanded form, particularly if long distances are involved. The beads can then simply be expanded near the site of application in boiling water in a cooking pot (Fig. 1.101). The unexpanded beads are added to the water a cupful at a time, stirred, and then removed from the water surface with a sieve. With this method the beads expand to only 15 - 20 times their volume. It is important to keep the unexpanded beads sealed until the expansion process is undertaken, in order to avoid leakage of the pentane, since this would reduce their final size.

Beads with a diameter of 2 mm when expanded are the best for controlling mosquito larvae. Thirty litres of beads (about three bucketfuls) weigh about 1.25 kg and are sufficient to cover 3 m^2 of water (as in a typical pit latrine) with a layer 1 cm thick.

Environmental manipulation

In contrast to the environmental modification methods, methods of environmental manipulation have to be repeated to remain effective. They are usually directed against one particular mosquito species and depend largely on its behaviour. While such measures may be very simple and cheap they should be applied only after careful study of the vector. Mosquito control experts may be needed to advise communities and health organizations on the method that is most appropriate locally.

Fig. 1.101. Unexpanded polystyrene beads can be expanded near the site of application in boiling water in a cooking pot.

Water-level fluctuation

Fluctuation of the water level in large reservoirs of drinking-water or irrigation water reduces mosquito breeding by:

- stranding the larvae at the margins;

- dislodging larvae from vegetation along the shoreline so that they are more exposed to wave action and fish;

- reducing the growth of plants along the margins between which larvae could find shelter.

The interval between the fluctuations must be less than the life of the larvae, i.e. about 7 - 10 days. The difference in water levels should usually be 30 - 40 cm (see p. 156).

Intermittent irrigation is used to control mosquitos in rice-growing areas (see p. 163).

Flushing (stream sluicing)

The principle of flushing is similar to that of water-level fluctuation. It is employed in small streams where there is a continuous and abundant supply of water flowing slowly enough to permit mosquitos to breed in quiet places along the margins. A periodic discharge of a large volume of water washes away the eggs, larvae and pupae from the edges or strands them on the banks.

In order to collect the water needed for flushing, a small dam is constructed upstream of the area where breeding occurs. The dam site should be at a point where the stream or channel is narrow and the banks are high. The dam should have a hand- or machine-operated sluice gate or an automatic siphon, to release the water at least once a week. The method requires high initial investment but is long-lasting and requires little maintenance. It has been used in tea and rubber plantations in south-east Asia to control *Anopheles minimus* and *A. maculatus*.

Changes in water salinity

Mosquitos that breed in lagoons and coastal marshes can be controlled by letting in additional seawater. Most species will not be able to tolerate the increase in salt concentration. The connection between sea and lagoons can be made with tide-gates (see box, p. 157) or simple drains or culverts.

Shading of stream banks

Where mosquitos prefer breeding sites that are partly or fully exposed to sunlight, they can be controlled by planting shrubs and trees along the banks of streams to provide dense shade. The method has been used successfully in tea gardens in Assam, India, to control *Anopheles maculatus* and *A. minimus*.

Clearing of vegetation

Clearing of vegetation may result in increased breeding by mosquito species that prefer sunlit water. However, some species need shaded water and may be effectively controlled, as is the case with *Anopheles balabacensis* in Sabah, Malaysia. This method may also be effective in removing resting places for adult mosquitos. In addition, it promotes evaporation and the drying up of small accumulations of water and makes breeding sites more visible for control purposes.

Removal of water plants

The larvae and pupae of *Mansonia* attach themselves to the submerged parts of water plants on which they depend for breathing. In ponds and swamps where *Mansonia* is a problem it can be controlled by periodically removing or destroying the vegetation (see p. 159). Other mosquito species can be controlled by removing vegetation which provides larvae with a safe hiding place from larvivorous fish as well as protection from wave movement and currents. In small breeding sites, such as borrow-pits and ponds, the vegetation can be removed manually, for example by the members of nearby communities, using rakes and other simple equipment. For somewhat larger sites, the vegetation can be removed by the application of herbicides or the introduction of herbivorous fish, e.g. the grass carp (see p. 159).

Sometimes, as for instance in swamp forests in parts of Indonesia and Malaysia, the removal or destruction of vegetation is impracticable because of the large size of the breeding area.

Straightening and steepening shorelines

Shorelines of streams, ditches and ponds can be modified to reduce the availability of shallow places suitable for breeding of mosquitos and to increase the flow of the water.

Biological control

The biological control of mosquitos and other pests involves introducing into the environment their natural enemies, such as parasites, disease organisms and predatory animals. They may include insects, viruses, bacteria, protozoa, fungi, plants, nematode worms and fish. The effective use of these agents requires a good understanding of the biology and behaviour of the insects to be controlled as well as of local environmental conditions. Such methods may be most effective when used in combination with others, such as environmental manipulation or the application of larvicides that do not harm the biological control agents.

Several organisms have proved effective against mosquito larvae. The most important are:

- fish that eat mosquito larvae (larvivorous fish);

- predatory mosquitos of the genus *Toxorhynchites*, the larvae of which feed on other mosquito larvae;

- dragonflies, the larvae of which feed on mosquito larvae;

- cyclopoid copepods, small crustaceans that attack first- and second-instar larvae of mosquitos;

- nematode worms that are parasites of mosquito larvae;

- fungi that grow in the bodies of mosquito larvae;

- bacterial larvicides, the toxic products of the bacteria *Bacillus thuringiensis* H-14 and *B. sphaericus*;

- neem, an oil extract of seeds of the neem tree, *Azadirachta indica*, which has larvicidal properties;

- *Azolla*, a free-floating fern that can completely cover water surfaces and prevent breeding by mosquitos.

Of these methods only two have become widely employed: the use of larvivorous fish and the use of bacterial larvicides; the latter are discussed in the section on larvicides.

Larvivorous fish

Larvivorous fish feed on mosquito larvae. They have been widely used around the world in attempts to control malaria, other mosquito-borne diseases and mosquito nuisance.

Suitable species of fish usually have the following characteristics:

- preference for mosquito larvae over other types of food located at the water surface;
- small size to allow access to shallow water and penetration into vegetation;
- high reproduction rate in small bodies of water;
- tolerance to pollution, salinity, temperature fluctuations and transportation;
- they should preferably originate from the region where control is to be effected.

Locally collected fish have been evaluated for their efficacy in controlling mosquitos and a number of species have proved useful. Most of them are tooth carp (Poeciliidae and Cyprinodontidae), small fish including many popular aquarium species. The juvenile stages, but not the adults, of some larger species may also eat mosquito larvae. Some of the most successful species to have been introduced into different countries are the top minnow or mosquito fish (*Gambusia affinis*) and the guppy (*Poecilia reticulata*). *Gambusia* is most efficient in clean water, while *Poecilia* can be used successfully in organically polluted water (*141*, *142*). *Poecilia* tolerates higher temperatures than *Gambusia* and may therefore be more effective in rice fields in hot areas. However, unlike *Gambusia*, it cannot survive temperatures below 10 °C. The annual killifishes, *Cynolebias*, *Nothobranchius* and *Aphyosemion*, have drought-resistant eggs and could be used in breeding sites that temporarily dry out, such as borrow-pits and irrigated rice fields (*143*).

The original geographical distribution of some larvivorous fish belonging to the tooth carp family (Cyprinodontidae)

Tropical and subtropical Africa

Aphanius
Aphyosemion
Epiplatys
Nothobranchius

India and south-east Asia

Aplocheilus
Macropodus

Central and South America

Fundulus
Jordanella
Rivulus
Gambusia
Girardinus
Heterandria
Poecilia (*Lebistes*)
Limia

Cynolebias

The importation of exotic fish species should be avoided and an evaluation should be made of the suitability of local species. When released in the natural environment, imported species may cause unwanted side-effects by replacing local species or affecting other aquatic animals. However, such fish can be freely used in man-made breeding habitats giving no access to the natural environment. Examples of such places are: water tanks and cisterns for the storage of drinking-water, swimming pools, garden ponds and water reservoirs in desert locations. These places can be stocked with *Gambusia* without risk of escape into nature.

Advantages and disadvantages of the use of larvivorous fish

Advantages

- In a suitable environment the larvivorous fish may establish themselves and provide a self-perpetuating larval control method.

- The cost of introducing and maintaining the fish is generally low and no complicated or expensive equipment is needed.

- The fish are environmentally clean and do not render water unsuitable for drinking.

Disadvantages

- They are only effective when large numbers eventually establish themselves and even then they do not always provide total control. Mosquitos may continue to breed at low densities. For complete control other measures have to be added, such as the use of larvicides that do not harm the fish.

- Larval control with fish may take 1 - 2 months; the method is therefore not suitable when quick results are needed.

- The fish are less effective in waters with much vegetation or floating garbage; when these are present, they must be removed.
- The fish have to be reared in special ponds; transportation and stocking require special care.

In ponds and marshes with dense aquatic vegetation, larvivorous fish are not very effective because of the difficulty of finding mosquito larvae. Bigger fish such as the carp (*Cyprinus carpio*) (*144*), the giant gourami (*Osphronemus goramy*) (*145*) and the tilapia (*Tilapia* or *Oreochromis mossambicus*) (*146*) can enable the larvivorous fish to reach the larvae by uprooting and eating vegetation. The bigger fish can also serve as an additional food supply for local populations (*147*). In some countries, fish are being reared both for consumption and as predators of mosquito larvae in various types of habitats. Cichlid fish, such as *Oreochromis mossambicus*, *O. niloticus* and *O. spiluris* have proved suitable for this purpose in Indonesia, Malaysia, Somalia and Sudan (*148*, *149*). The common carp, *Cyprinus carpio*, and the grass carp, *Ctenopharyngodon idella*, have been used with success in south India (*144*) and China. Larvivorous fish can also be used as food for the bigger fish that serve as food for the human population.

Rearing larvivorous fish

In regions where larvivorous fish frequently occur in particular habitats, these can be used as a source of fish for introduction into mosquito breeding places. This is the usual method in relatively dry areas where water is limited to canals, ditches, wells and so on. Although large numbers of fish may not always be available, this system should lead to widespread colonization with fish (*150*, *151*).

To guarantee a regular supply of fish it is necessary to rear them in large quantities in special breeding ponds. Fish ponds are already widely used for the cultivation of fish for food and they can be simultaneously used for rearing larvivorous fish. Dykes can be built up from the soil excavated to make the pond. The dykes are built in layers of about 20 cm and each layer should be dampened and rammed down before a new layer is added. Grass and other vegetation on the dykes can serve as protection against erosion. The top of the dyke should be at least 30 - 50 cm above the water level. Large cement tanks have also been used successfully for rearing fish. Adequate space and aquatic vegetation are needed to protect the young fish from older fish. Communities can rear their own stock of larvivorous fish and distribute them to farmers and householders. Judicious artifi-cial feeding with organic waste material, animal manure and so forth can increase production. The proliferation of algae, which consume much oxygen, should be avoided, possibly by the use of a herbicide.

Transportation and distribution

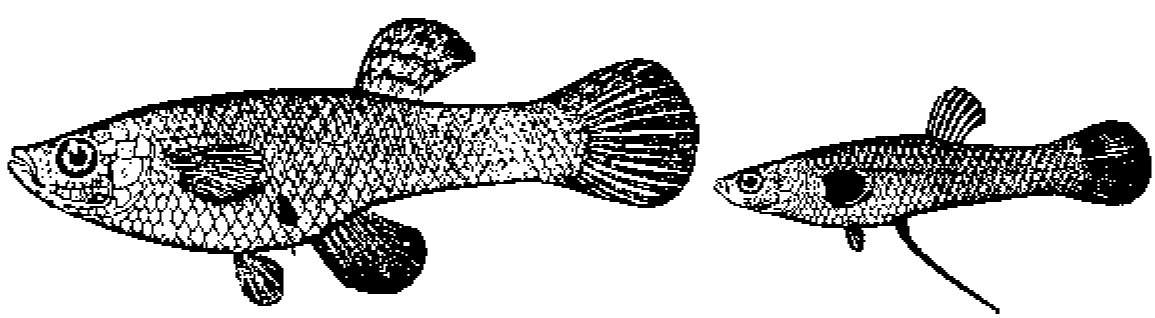
The fish are best transported in small containers of up to 40 litres, such as plastic buckets and jerry cans, or in strong plastic bags, half-filled with water from the rearing pond (Fig. 1.102). Water from the new location should be added before the fish are released, to avoid the shock of a sudden change in water temperature or quality. If transportation lasts several hours or more, special care should be taken to maintain the oxygen supply in the water and to prevent major changes in temperature. Containers should be closed with about a third of their volume occupied by air. The number of fish per bag or container should be kept low and the bags or containers should be wrapped in wet cloth or placed in cardboard or wooden boxes or in polystyrene boxes with some temperature control. To supply fish to small mosquito breeding places in a community, buckets can be used containing, for example, 50 *Gambusia* in 8 litres of water. Six *Gambusia* are sufficient for a pool of 5 - 10 m^2 which has few aquatic plants (*151*).

Fig. 1.102. Fish can be carried from a breeding pond to where they are needed in a plastic bag half-filled with water.

Effective larvivorous fish species

The mosquito fish or top minnow, Gambusia affinis

This species is the most widely used against mosquito larvae. Together with the guppy it belongs to the live-bearing tooth carp family, Poeciliidae. Their mouths are adapted to feeding from the surface. It originates from Central America but, because of its success in controlling mosquitos, has been introduced into many parts of the world. These fish can withstand large fluctuations in temperature as well as pollution of the water, but they are most productive in relatively clean water of moderate temperature (*152*).

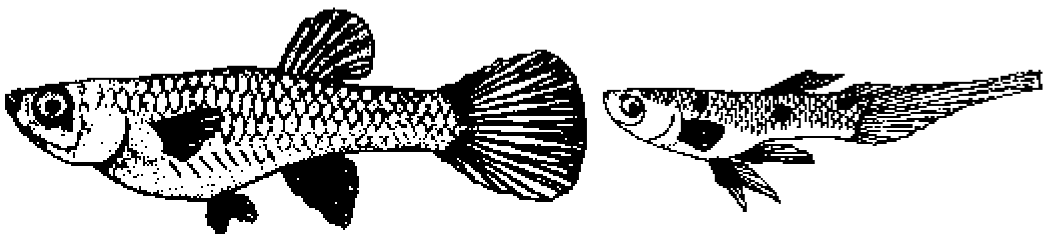


Figure

actual size (reproduced from *152*)

The guppy, Poecilia reticulata

Similar to the mosquito fish, this is a live-bearing tooth carp that is adapted to taking food from the surface. It originates from South America and has become very popular as an aquarium fish. It has been introduced for mosquito control in many countries, especially in South America and Asia. The species prefers higher temperatures than the mosquito fish and can withstand highly polluted water. It has therefore been most successful against *Culex* mosquitos which breed in organically polluted water (*153*).



Figure

actual size (reproduced from *153*)

The panchax, Aplocheilus panchax

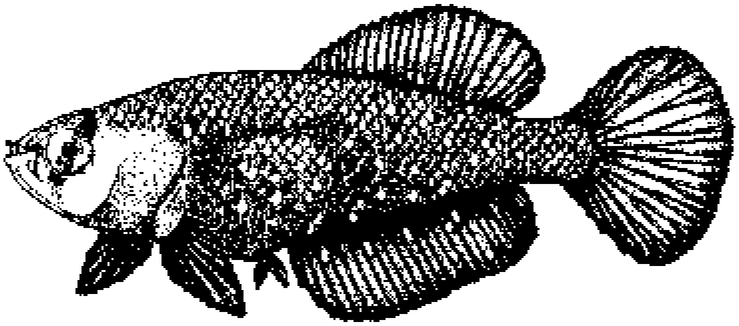
This egg-laying tooth carp is found in the Indian subcontinent, Indonesia, Malaysia and Sri Lanka, where it commonly occurs in paddy fields and ditches and is important in the control of mosquitos (*154*). The fish can withstand pollution and water temperatures between 20 °C and 45 °C.

Figure

actual size (reproduced from *154*)

The Argentine pearlfish, Cynolebias bellotii

This is one of the annual fishes that occur in South America and Africa, known as instant fish. They cannot reproduce in permanent water bodies and occur only in habitats where the water disappears every 2 - 3 months or at least once a year. The eggs, which survive the dry period buried in the soil, may be concentrated, transported and dispersed in slightly damp material. They hatch within a few hours after flooding. Although not extensively evaluated, these fish may be useful in borrow-pits and temporary dry pools as well as in rice fields and irrigated pastures where other fish cannot survive (*153*).

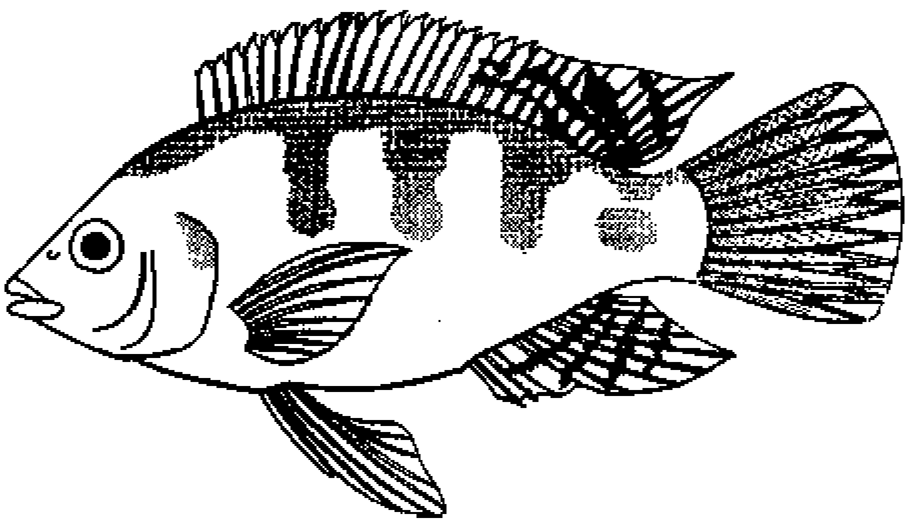


Figure

actual size (reproduced from *153*)

The Mozambique mouthbrooder, Oreochromis (*Tilapia*) *mossambicus*

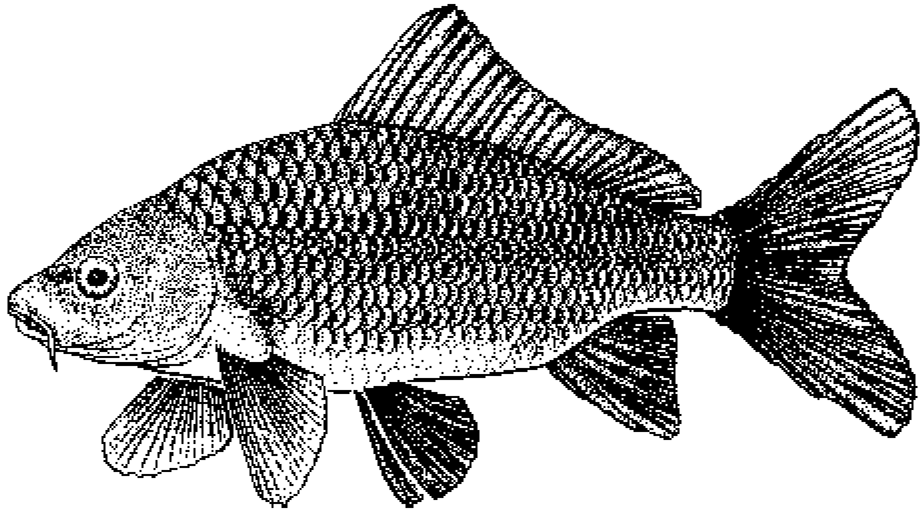
This cichlid fish occurs in East Africa. It has been reared successfully in irrigated rice fields where it was used both to control mosquitos and as a source of food. With an optimal temperature of 22 °C it reproduces very rapidly. The species can live and reproduce in fresh and brackish water (*146*).



Figure

(shown at 40%, actual size is 20 cm; © WHO)

This edible fish can be reared in irrigated rice fields, ditches and ponds; it is hardy and prefers rich, shallow waters with muddy bottoms and good aquatic weed growth. The species multiplies when the water temperature is over 18 °C. The fingerlings feed on mosquito larvae, the adults on aquatic vegetation, weeds and algae but not on rice plants. The carp can be used to control both mosquitos and weeds (*153*).



Figure

(shown at 25%, actual size is 32 cm; reproduced from *153*).

Larvicides

Larvicides are applied to mosquito breeding sites to kill larvae. By the end of the nineteenth century, petroleum oils were being used to control mosquitos even before their role in disease transmission was discovered; the arsenical compound Paris green was also blown as a powder over water to kill surface-feeding anopheline larvae. These larvicides have largely been replaced by newer products, although oils are still being used on a small scale. The advantages and disadvantages of larvicides are given on p. 130. Larvicides may act as stomach poisons, which must be ingested by the larvae while feeding, or as contact poisons, which penetrate the body wall or the respiratory tract. Larvicides are used on breeding sites that cannot be drained or filled and where other source reduction methods or the use of larvivorous fish would be too expensive or impossible.

Paris green

Paris green (copper acetoarsenite) is an arsenical compound that was used extensively from 1921 until the 1940s to control anopheline larvae. A green powder, it is practically insoluble in water. The particles float on the surface where they poison the surface-feeding anopheline larvae. Other mosquito species are usually unaffected. Its advantages were low cost, high effectiveness against anopheline larvae, portability and ease of distribution. No ill effects were recorded in animals, fish and insects, and treated water remained suitable for domestic use. It was an important tool for many malaria control programmes but its use diminished after the introduction of the relatively safe and highly effective organophosphorus compounds.

Petroleum oils

The application of oil to water surfaces in order to kill larvae was one of the earliest mosquito control methods (*155*, *156*). The larvae are killed in two ways when they rise to the surface to breathe: by suffocation and by poisoning with toxic vapour. Larvicidal oils are not effective against *Mansonia* mosquitos because their larvae and pupae do not come to the surface. The oil should be applied in a thin film completely covering the surface. Many different grades of oil may be suitable for mosquito control, depending on local conditions. At higher temperatures a thicker oil is required, e.g. crude or fuel oil, while in the presence of vegetation a lighter oil with greater spreading power, e.g. kerosene or diesel oil, is necessary. The oils kill larvae very quickly but last only between a few hours and several days. Because of their relatively high cost compared with some other larvicides and because of their limited persistence, their use for mosquito control has decreased. They are of special interest in situations where mosquitos have developed resistance to insecticides. For small-scale applications by individual households or communities, they offer the advantage of wide availability.

Locally available oils

For the treatment of small water surfaces, as in wet pit latrines, a small quantity of fuel oil or waste oil from a garage may be appropriate. Detailed specifications are available on many different larvicidal oils suitable for large-scale applications (*151*) but in practice the user is often limited to materials that are obtainable locally in large volumes and at moderate prices. Diesel oil and kerosene (paraffin) are generally available and equally effective. About 140 - 190 litres of diesel oil have to be applied per hectare, making the method rather expensive. The cost can be reduced by 20 - 75% if a spreading agent (detergent) is added to diesel oils, fuel oils or kerosene so as to improve the penetration in vegetation and polluted water. Octoxinol is such an agent and is effective at 0.5% in oil. Alternatively, the addition of 1 - 2.5% vegetable oil, such as castor oil or coconut oil, can be used to increase spreading power. Between 18 and 50 litres of such oils per hectare may be sufficient. The exact quantity required for control depends primarily on the amount of vegetation and debris on the surface and on the degree of pollution of the water.

Commercial oils

Specially prepared commercial oils have been developed which contain surface-active agents that increase spreading power and toxic action. These oils may be effective at 9 - 27 litres/ha. The addition of temephos may increase effectiveness. Properly used, the lighter oils are non-toxic to fish, birds and mammals.

Application

The oils can be applied simply by dripping from a can or bucket or pouring from a watering-can. For large-scale applications it is better to use hand-compression sprayers. Very large areas may be sprayed from the air.

Advantages and disadvantages of the use of larvicidal oils

Advantages

- The oil is visible on the water surface and so it is possible to see whether it has been applied properly.

- For small surfaces such as borrow-pits, pools, latrines, drains and soakaway pits, it is a relatively cheap method and easy to apply.

- Mosquitos cannot develop resistance against this method.

- At recommended dosages there is no toxicity to mammals, fish and most other non-target organisms.

Disadvantages

- For large surfaces the method is costly.

- It is not very effective in the presence of vegetation and floating debris, which therefore has to be removed before the oil is applied.

- The effect usually lasts only a few days.

- The oil coats vegetation, tree trunks and so on.

- Under windy conditions the oil will be dispersed.

Synthetic organic larvicides

The discovery in the 1940s of the organochlorine insecticides led to the abandonment in most places of traditional mosquito control methods and the adoption of the spraying of breeding sites with the new compounds. In the course of the 1950s the organochlorine insecticides lost much of their effectiveness in many places as a result of the development of resistance by some mosquito species. It also emerged that the organochlorines were very persistent in the soil and in tissues of plants and animals. These insecticides are no longer recommended by WHO for the control of mosquito larvae, although with the exception of dieldrin they can still be used safely for spraying walls in houses. The organophosphorus compounds, the carbamates and the pyrethroids are less persistent, breaking down quickly in the environment, and they are therefore recommended as larvicides. However, the pyrethroids are very toxic to fish and should not be used where there are fish or crustaceans. Water contamination with these larvicides is temporary and most of the chemicals disappear from water within a day, although the organo-phosphorus compounds may persist much longer.

In situations where mosquitos have developed resistance to all the conventional larvicides, consideration may be given to using larvicidal oils, the more expensive insect growth regulators, or bacterial larvicides as alternatives. The last two groups are non-toxic to fish, mammals and most other non-target organisms in the environment. Formulated as slow-release briquettes they show better residual effectiveness in stagnant bodies of water of relatively small volume than any of the other available larvicides.

Among the most commonly used larvicides are the organophosphorus compounds, such as temephos, fenthion and chlorpyrifos (Table 1.5).

Table 1.5. Compounds suitable as larvicides in mosquito control

Larvicide	Formulation[a]	Dosage of active ingredient (g/ha)[b]	Duration of effective action (weeks)	Toxicity/hazard of active ingredient[c]
Petroleum oils				
Diesel oil	S	140 - 190[d]	1 - 2	U
Larvicidal oil	S	19 - 47[d]	1 - 2	U
Paris green	GR	840 - 1000	1 - 2	High
Organophosphorus compounds				
Chlorpyrifos	EC, GR, S, WP	11 - 25	3 - 17	Moderate
Fenitrothion	EC, GR	100 - 1000	1 - 3	Moderate
Fenthion	EC, GR	22 - 112	2 - 11	High
Jodfenphos	EC, GR, S	50 - 100	7 - 16	U
Malathion	EC, GR, S	224 - 1000	1 - 2	Slight
Pirimiphos methyl	EC, GR, S	50 - 100	1 - 11	Slight
Temephos	EC, GR, S	56 - 112	2 - 4	U
Insect growth regulators				
Diflubenzuron	GR, WP	25 - 100	1 - 4	U
Methoprene	BR, S, SRS	100 - 1000	4 - 8	U
Pyriproxyfen	GR	10 - 100	4 - 8	U
Bacterial larvicides				
Bacillus thuringiensis H-14	BR, EC, GR, WP	100 - 6000	1 - 2	U
B. sphaericus	BR, EC, GR	500 - 5000	2 - 8	U

[a] BR = briquettes; EC = emulsifiable concentrate; GR = granules; S = suspension; SC = suspension concentrate; SRS = slow-release suspension; WP = wettable powder.

[b] The highest dosages are for use in polluted water and for residual effect.

[c] U = unlikely to present acute hazard in normal use.

[d] Litres per hectare.

Source: reference *157*.

Advantages and disadvantages of larvicide application

Advantages

- Mosquitos are destroyed before they disperse to human habitations.

- The operations can be carried out in a very short time.
- Many effective larvicides are widely available.
- For small-scale treatments, larvicides can be applied by hand; for larger-scale treatments use can be made of agricultural sprayers or the hand-spray pumps widely used in antimalarial house-spraying programmes.

Disadvantages

- Control is temporary and frequent repetition could be costly in areas with many or extensive breeding sites.
- Some larvicides may harm other organisms in the environment, including the natural enemies of mosquito larvae.
- The larvicides may be toxic to humans; consequently, training in technique and safety precautions is necessary for those who apply them.

Larvicide formulations

Most larvicides are available in the following formulations:

- *Wettable powder*. A dry powder of the insecticide treated with a wetting (dispersing) agent to permit quick mixing with water to form a suspension that can be sprayed; easy to store and transport.
- *Suspension concentrate*. A liquid containing finely divided insecticide particles, a wetting agent and water; it is mixed with water to make a water-based suspension for spraying.
- *Emulsifiable concentrate*. A solution of insecticide in a special solvent; the addition of emulsifiers enables it to be easily diluted with water. Application involves pouring out over the water surface or spraying.
- *Granules and pellets*. Inert materials, such as grains of sand or absorptive materials, coated or impregnated with insecticide. Granules and pellets are relatively heavy and penetrate dense growth of water plants better than liquid formulations. Some types sink to the bottom of the breeding site, while others float on the water surface where they are more effective against surface-feeding *Anopheles* larvae. Some allow rapid release of the active ingredient, others permit slow release. Application is by hand or with portable blowers. Granules are heavy and may pose transportation problems for large-scale applications. They are often made locally by mixing sand or other carrier materials with the insecticide solution.
- *Briquettes*. This is a block of an inert matrix material impregnated with insecticide; it floats on the water surface and slowly releases the active ingredient. Briquettes are applied by hand.

The most commonly used formulations are the emulsifiable concentrates, which are usually applied with a portable sprayer; wettable powders and suspension concentrates can be applied in the same way. In large-scale programmes, spraying is often carried out with machines mounted on vehicles. Aircraft are sometimes used to spray very large or inaccessible areas. For small-scale operations the material can be distributed by hand. Liquid can be poured from a bottle, can or bucket over the water surface. Granules can be spread by hand. Direct contact between skin and insecticide should be avoided by using gloves. Because most products have a very limited residual effect when used as larvicides they have to be reapplied every 1 - 2 weeks in most tropical areas.

Temephos

Temephos, an organophosphorus compound, is highly active against mosquito larvae and other aquatic insects, while its toxicity to fish, birds, mammals and humans is very low. Its low toxicity to non-target organisms and low effective dosage make temephos the most appropriate larvicide in many situations. It is recommended for the control of mosquito larvae in drinking-water and in areas where vertebrates may come into contact with it (*155*, *158*, *159*) and has been widely used in rivers in West Africa for the control of blackfly larvae. It is also effective in polluted waters. It is commonly available as emulsifiable concentrate (46% and 20% (w/v) active ingredient) and granules (1% active ingredient).

Application

Large surfaces: granules and water suspensions of the emulsifiable concentrate are applied by spraying. The target dosage should be 55 g of active ingredient per ha on relatively clean open water and 110 g of active ingredient per ha where there is dense aquatic vegetation. The granules are more effective where there is dense vegetation and should be applied at intervals of 1 - 3 months.

Small surfaces: small quantities of granules can be added to drinking-water containers, where they remain effective for about five weeks. The recommended dosage in drinking-water is 0.5 - 1 mg of active ingredient per litre, which corresponds to 20 g (two teaspoonfuls) of a 1% sand granule formulation in a 200-litre drum. Liquid formulations can be applied by pouring the appropriate quantity from a can or bucket on to the water surface.

Floating plastic pellets impregnated with temephos are currently being tested. This formulation remains effective for up to six weeks and is of particular relevance to the control of *Anopheles* larvae, which feed on the surface.

Fenthion

Fenthion is an organophosphorus compound with a quick killing action on larvae and a long residual effect. The compound has a relatively high toxicity to humans, mammals and birds, and precautions should be taken (see Chapter 10). At normal dosages for larval control, fish are not affected. It is mainly applicable to polluted water in ditches, ponds, swamps, septic tanks and other mosquito breeding sites that are not used as drinking-water supplies by humans or domestic animals. In polluted water, fenthion is more effective than freshwater larvicides such as temephos and methoprene. Frequent applications in certain areas have caused resistance to develop in some species of target insects, especially *Culex quinque-fasciatus*. Fenthion is commonly available as emulsifiable concentrates (46% and 84.5% (w/v) active ingredient) and sand granules (2% active ingredient).

Application

Large surfaces: spray is applied at a dosage of not more than 112 g of active ingredient per ha. The final concentration in treated water should not exceed 0.1 mg/litre. Emulsifiable concentrates can be applied directly or after mixing with water. The 2% sand granules are applied using a portable blower at 5.5 kg/ha and are preferred for treating areas with dense vegetation or with a layer of floating debris. Granules are used in shallow water and slow-moving streams that are not more than 30 cm deep.

Small surfaces: the emulsifiable concentrate formulation can be poured directly into ponds, small ditches, septic tanks, etc. With the 46% emulsifiable concentrate, 0.2 ml should be used per cubic metre of water, corresponding to 0.1 mg of fenthion per litre. For application with a hand-compression sprayer, 10 ml of the 46% emulsifiable concentrate should be mixed with 10 litres of water. Two litres of this mixture should be sprayed per 100 m^2 of water with a depth of about 10 cm. The granules should be applied by hand, using gloves, at 1.25 g/m^2 of water surface not deeper than 50 cm.

Malathion

Malathion, an organophosphorus compound, is effective against a great variety of insects. Although primarily used as a residual spray against adult mosquitos, it also kills mosquito larvae in breeding sites in sprayed areas. It is particularly effective against *Aedes aegypti* in urban areas. At the usual dosages (224 - 1000 g/ha) it is considered safe for humans and domestic animals in the treated areas, but it may cause harm to fish.

Various formulations are available but they are not routinely used for the control of larvae and are applied only by specialized mosquito control agencies.

Chlorpyrifos

This organophosphorus compound is commonly used as a larvicide in moderately to highly polluted water, where it has a residual effect lasting up to several weeks (*157*). It is used successfully in catch basins, ditches containing sewage, pit latrines, cesspits and sewage collection and treatment sites. It is highly toxic to fish and moderately toxic to mammals and birds. It should therefore never be used in water used for drinking or containing fish, and should be handled only by people trained in the safe use of insecticides (see Chapter 10).

Chlorpyrifos is commonly available as emulsifiable concentrate (48% (w/v) active ingredient), granules and wettable powder.

Application

Hand-compression sprayers are used to apply 11 - 25 g of active ingredient/ha (*157*).

Pirimiphos methyl

Pirimiphos methyl is an organophosphorus compound, effective against a large variety of insects, including mosquito adults and larvae. It has levels of activity similar to those of fenthion but is much less toxic to humans. However, it cannot be used for the treatment of drinking-water. It is relatively unstable in polluted water. It is commonly available as a 50% emulsifiable concentrate.

Application

Hand-compression sprayers are used to apply 100 g of active ingredient per hectare. The treatment remains effective for 1 - 11 weeks, depending on water quality.

Pyrethroids

Pyrethroids such as deltamethrin and permethrin can be used as mosquito larvi-cides. However, because they have serious effects on all insects, fish, crustaceans and aquatic animals in general, their use should be limited to special cases only, under the close supervision of specialized mosquito control agencies.

Insect growth regulators

Insect growth regulators are chemical compounds that are highly toxic to insect larvae or pupae, interfering with their development into adults. They have a very low toxicity to mammals, birds, fish and adult insects, but are highly toxic to crustaceans and immature stages of aquatic insects. Their use is limited by their high cost and restricted availability, but they may be of particular interest where target insects have developed resistance to the organophosphorus larvicides or where these compounds cannot be used because of their effect on the environment. Insect growth regulators may not be acceptable where immediate killing of larvae is required, for instance where householders are legally obliged to control mosquito larvae on their premises. They break down rapidly in the environment but they may last between several weeks and several months when applied as granules, microcapsules or briquettes. They can be divided into the two following groups.

- *Juvenile hormone analogues*, e.g. methoprene, prevent the development of larvae into pupae or of pupae into adults; they do not kill larvae.

- *Chitin synthesis inhibitors* interfere with the moulting process, killing the larvae when they moult. They thus act more rapidly than the juvenile hormone analogues. Examples are diflubenzuron and triflumuron.

Safety

Although insect growth regulators are unlikely to pose a threat to humans or domestic animals, they can disturb the development of various species of arthropod living on the breeding sites where they are used. Most manufacturers therefore advise their use only on aquatic sites where there is a low risk to populations of crabs, shrimps and other non-target arthropods through direct application, run-off or drift.

Methoprene

Methoprene is considered by WHO to be safe for use in drinking-water (*160*). The active ingredient is fairly rapidly decomposed in water. Briquettes containing 1.8-8% methoprene and granules of various concentrations have been devised to obtain a longer residual effectiveness. The briquettes release methoprene slowly over a period of up to four months in stagnant water in containers but for considerably shorter periods in flowing water. If a breeding site dries up, the briquettes may remain effective until it is flooded again (*161*). In anticipation of flooding or rains they can be applied to dry places known to be potential breeding sites. The treatment of ground pools in Kenya five weeks before flooding with rainwater effectively controlled mosquito breeding in the month following the rains (*162*, *163*). The main advantage of such pretreatment of breeding sites is that it can be done in areas that become inaccessible during the wet season. Target areas are ditches, drains, catch basins, pools, tidal marshes, freshwater swamps and borrow-pits. The briquettes are unlikely to be effective in sites where they can be removed by flushing. In muddy areas the briquettes may become clogged and this reduces their effectiveness.

Application

The briquettes are applied by hand; no equipment is needed. For this reason they are particularly suitable for application in remote areas, in breeding sites where a long residual effectiveness is required. They should be placed in the deepest part of a breeding site so as to maintain control during the dry season. For *Aedes*, 4 - 6 kg of active ingredient should be applied per ha. One briquette should be placed per 20 m^2 in shallow pools (less than 60 cm deep) where the water is stagnant. For the other mosquitos, such as *Anopheles, Culex* and *Mansonia*, the dosage should be doubled.

Diflubenzuron

Diflubenzuron is used mainly for spray-on application to mosquito breeding sites in open water, whether clear or polluted. It is suitable for use in irrigated fields with food crops. It may last for 1 - 2 weeks but in closed systems, such as cesspits or latrines, the effect may persist for up to a month. It has also been used to control the breeding of biting midges in swampy areas. Diflubenzuron is commonly available as wettable powder (25% active ingredient) or as granules (0.5% diflubenzuron).

Application

The wettable powder is mixed with water and applied with spray equipment at a rate of 25 - 50 g/ha on clear water surfaces and 50 - 100 g/ha on polluted water surfaces. The granular formulation is used on breeding sites with heavy vegetation or flowing water. It is applied by hand or with portable blowers.

Bacterial larvicides

Bacillus thuringiensis H-14

The bacterium *Bacillus thuringiensis* serotype H-14 (*B.t.* H-14) produces toxins which are very effective in killing mosquito and blackfly larvae after ingestion. At normal dosages it is harmless to other insects, fish, higher animals and humans and is suitable for use in water used for drinking or for the irrigation of food crops. It is effective against insects that have developed resistance to chemical larvicides (*148*, *164*). It breaks down quickly in the environment and has to be reapplied periodically. The product is more expensive than most conventional larvicides but cheaper than the insect growth regulators.

B.t. H-14 is commonly available as wettable powder and granules. A briquette formulation has recently been developed which floats on the surface and releases *B.t.* H-14 for about 30 days. The effectiveness of the briquettes is not affected by alternate wetting and drying and they are therefore suitable for both permanent and temporary habitats. The briquettes, which are ring-shaped and have a diameter of about 5 cm, are intended for the treatment of small breeding sites in the domestic environment (*165*), such as ponds, basins and tanks, and for areas that are difficult to reach. On open water surfaces the briquettes are not very effective because winds may blow them to one side (*166*). Briquettes that have an insoluble matrix become ineffective in slightly polluted water because the matrix material becomes clogged; they can therefore only be used in clean water.

B.t. H-14 is generally referred to as providing biological control. However, the product contains mainly dead bacteria, living spores and toxic crystals in the spores which do not multiply, and it could therefore also be considered as a biologically produced insecticide.

Application

The wettable powder formulation is mixed with water and sprayed with hand-compression pumps or other spray equipment. Granules are applied by hand or with portable blowers to breeding sites covered with vegetation. Briquettes are applied by hand, using up to 4 per 10 m^2 of water surface. Where they are likely to be blown by the wind, they should be attached by string to plants, poles or other fixed objects (*167*). The briquettes should be stored in sealed packages in a cool place so as to protect them from humidity.

Bacillus sphaericus

Another bacterium, *Bacillus sphaericus*, also produces a toxin. It has characteristics similar to those of *B.t.* H-14 but is more effective in polluted water while *B.t.* H-14 is more effective in clean water. It is not effective against blackflies or *Aedes aegypti* (*148*, *164*). Unlike *B.t.* H-14 it is produced as a formulation containing living bacteria that multiply even in polluted water. *B. sphaericus* usually has a longer action than *B.t.* H-14. It is considered very suitable for the treatment of breeding sites of *Culex* mosquitos in polluted water (*165*). It has a higher residual effectiveness in such habitats than most other larvicides and offers the added advantages of safety to non-target organisms and lack of resistance (*168*). This method is still being developed but some products have already reached the market. In field tests, slow-release *B. sphaericus* pellets and briquettes have been found to be effective against mosquito larvae for over eight weeks (*165*). Granule, wettable powder and flowable or soluble concentrate formulations also exist.

Application

The soluble concentrate is thoroughly mixed with water and applied with a hand-compression sprayer. During spraying the tank has to be shaken from time to time. Dosages are dependent on the target species and type of water. To control *Culex* in small accumulations of stagnant water, the suspension should be applied at 0.1 - 10 ml/m^2. Residual activity may continue for 1 - 2 weeks at the lowest rate and for 2 - 3 months at the highest rate. Larger surfaces with polluted water are sprayed at 1 - 4 litres/ha.

Habitats in and around houses

Mosquito breeding places in and around houses can be divided into two main types:

- Breeding sites with clean water: mainly rain-filled receptacles in humid tropical areas which are suitable breeding sites for some *Aedes* species.

- Breeding sites with polluted water: mainly in on-site sanitation systems and bodies of stagnant and polluted water favoured by *Culex* species.

Measures to prevent breeding in and around houses are usually simple and based on source reduction. They can be implemented by householders on their own premises without expert advice.

Breeding sites with clean water

Most accumulations of clean water are only temporary. Rain-filled receptacles in gardens may dry out in a few days or weeks. These habitats are favoured by *Aedes aegypti*, which can act as a vector of dengue and yellow fever, and by *Aedes albopictus*, also a dengue vector and known in the Americas as the Asian tiger mosquito. These species also breed in containers that are used to store water for drinking or washing. While *Aedes aegypti* commonly breeds and feeds inside houses, *Aedes albopictus* is more common outside, in open spaces with shaded vegetation and suitable breeding sites such as car tyres and garbage dumps. *Anopheles stephensi*, a vector of malaria in some urban areas in south Asia, often breeds in wells, ponds, cisterns and containers used for the storage of drinking-water.

The breeding sites with clean water can be divided into two groups for which different control measures are needed:

- temporary breeding sites indoors and outdoors;
- permanent breeding sites in water storage containers, wells and pools.

Temporary breeding sites indoors

Breeding sites for *Aedes* mosquitos can be found in and around houses in flower vases, pot plants, pot-plant saucers and neglected ant traps (containers filled with water and placed under the legs of food cupboards) (Fig. 1.103). In vacant houses, breeding may occur in toilet bowls, toilet-flushing cisterns, and drains in bathrooms and kitchens.

Control measures

- Avoid excessive watering of pot plants.

- Change water in flower vases weekly and scrub to remove adhering mosquito eggs before refilling with fresh water. Temephos or fenthion sand granules can be added to flower vases and other temporary breeding sites (Fig. 1.104).

• Salt, temephos sand granules (p. 132) (Fig. 1.105) or a floating layer of oil (p. 128) can be added to the water in ant traps; alternatively the water may be replaced by grease.

• In vacant houses, toilet bowls and gully and floor traps should be covered and the overflow pipe of the flushing cistern should be made mosquito-proof with a piece of netting or cloth (Fig. 1.106). For shorter periods the use of a disinfectant or a larvicide might be advantageous (p. 150).

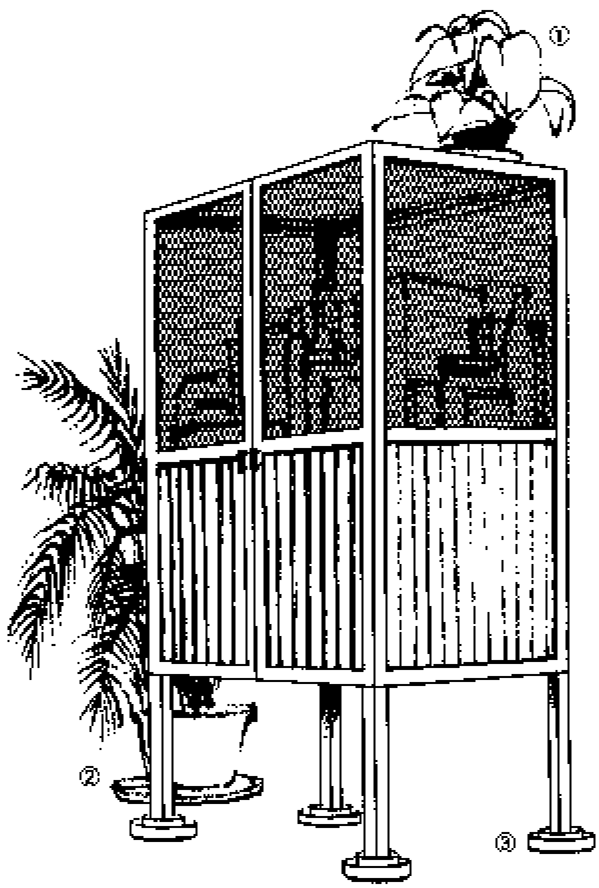


Fig. 1.103. *Aedes* can breed indoors in (1) pot plants, (2) pot-plant saucers and (3) ant traps.

Fig. 1.104. Temephos or fenthion sand granules can be added to flower vases.

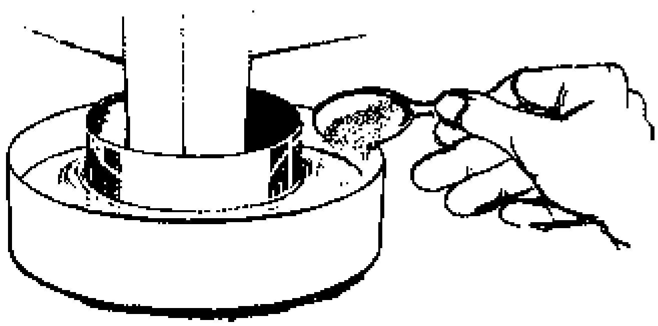


Fig. 1.105. Add salt or temephos sand granules to the water in ant traps.

Temporary breeding sites outdoors

Breeding sites can be found outdoors in rubbish, discarded tyres, discarded household and garden utensils, construction materials, roof gutters, water storage containers, drinking-water tanks, plants and various other objects (Fig. 1.107). If villages are located near a beach or river bank, breeding also occurs in water in the bottom of boats.

Control measures

- Small pools should be filled up with earth, stones or sand and levelled. Deeper rain-filled pools can be filled with rubble and covered with a layer of soil. Where there are many pools during the rainy season, rapid treatment with a suitable larvicide (p. 128) by spraying or hand application may be more practicable.

- Rubbish should be cleared up and disposed of through the local refuse collection system if one exists (Fig. 1.108). Communities may use refuse to fill borrow-pits, pools and other low-lying areas. Refuse should be covered regularly with a layer of soil to prevent flies, mosquitos and rodents from breeding. The final cover of compacted earth should be at least 50 cm deep and should have a slope of 1 - 5 cm per 10 m for drainage. Such sanitary landfills (p. 114) eliminate mosquito breeding, permit refuse disposal and improve land values. Landfill areas have been used for house construction, children's playgrounds and so on.

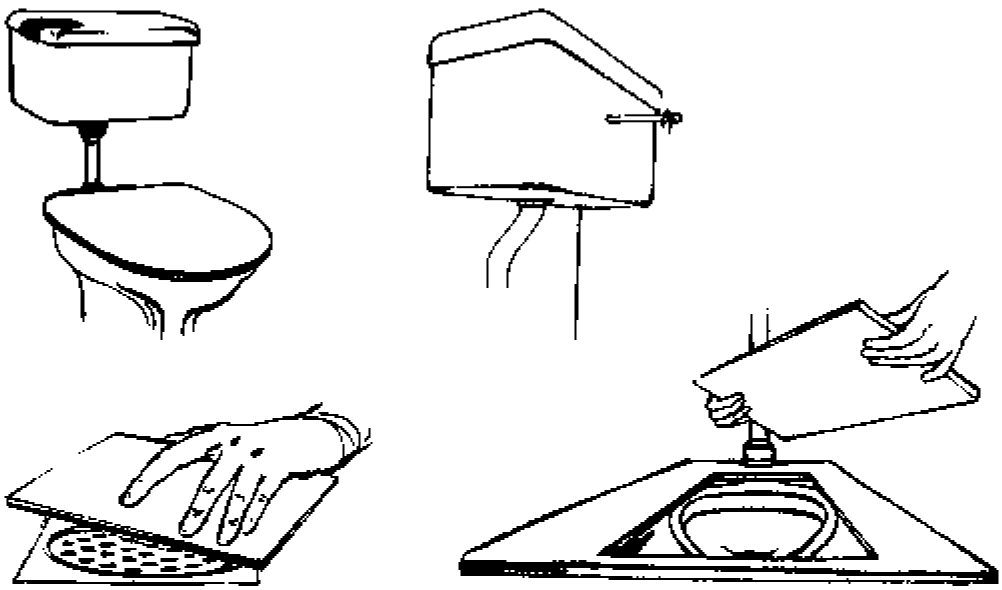


Fig. 1.106. Toilet bowls, floor traps and overflow pipes should be made mosquito-proof.

• Old tyres can be stored under a roof or cover to prevent the collection of rainwater (Fig. 1.109). Piercing a hole will also prevent the collection of water. Tyres can also be filled with soil and used as plant pots. The application of larvicides or oil (p. 128) to accumulations of rainwater in tyres kills larvae.

• Large objects such as old cars, refrigerators and washing machines are important breeding places and should not be left in the open where they can collect rainwater.

• Buckets, bowls and watering cans should be stored in a dry place, covered, or turned upside down.

• Construction materials should be covered with a plastic sheet or stored under a roof. Holes in construction blocks used as wall material should be filled with sand or cement (Fig. 1.110).

• Gutters should be inspected periodically. If necessary they should be cleaned (Fig. 1.111) or repaired with a suitable gradient (an inclination of about 1 cm over 10 m length) to avoid standing water.

• Tree holes can be filled with sand or concrete (Fig. 1.112). The leaf axils of banana trees and bromeliads often contain rainwater to which temephos (p. 132) can be applied.

• The open-ended stumps of bamboo fences should be cut down to the nodes (Fig. 1.113) or filled with sand to prevent the accumulation of rainwater.

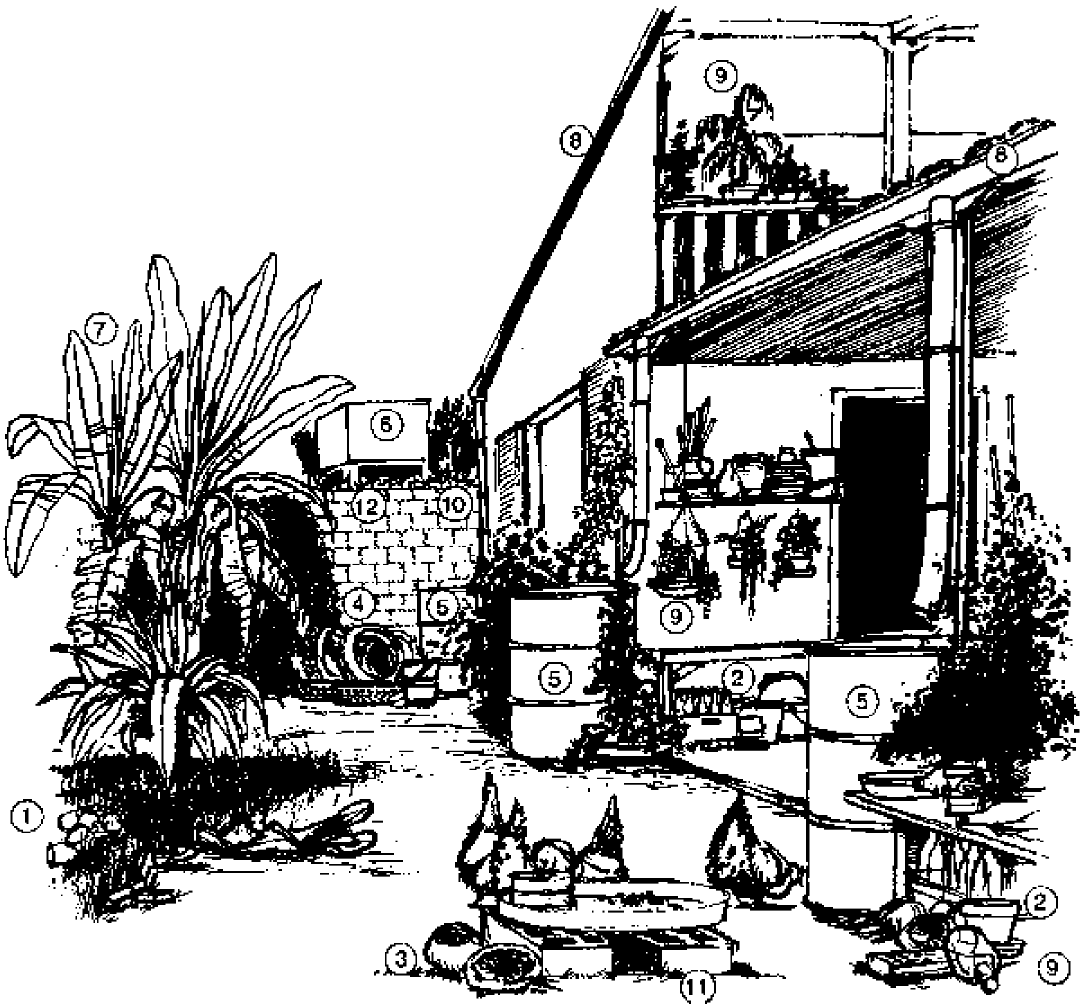


Fig. 1.107. Some examples of outdoor breeding places of *Aedes*. Breeding occurs in (1) discarded cans and plastic containers, (2) bottles, (3) coconut husks, (4) old tyres, (5) drums and barrels, (6) water storage tanks, (7) bromeliads and axils of banana trees, (8) obstructed roof gutters, (9) plant pot saucers, (10) broken bottles fixed on walls as a precaution against burglars, (11) holes in unused construction blocks, and (12) the upper edge of block walls.

Permanent breeding sites

Water storage containers

Jars, cisterns and water storage tanks provide suitable breeding places for *Aedes* species and *Anopheles stephensi*. The introduction of a reliable and properly designed piped water supply reduces dependence on water storage containers and should lead to a reduction in breeding sites. Measures to prevent breeding in water containers must not adversely affect water quality or interfere with the addition or removal of water.

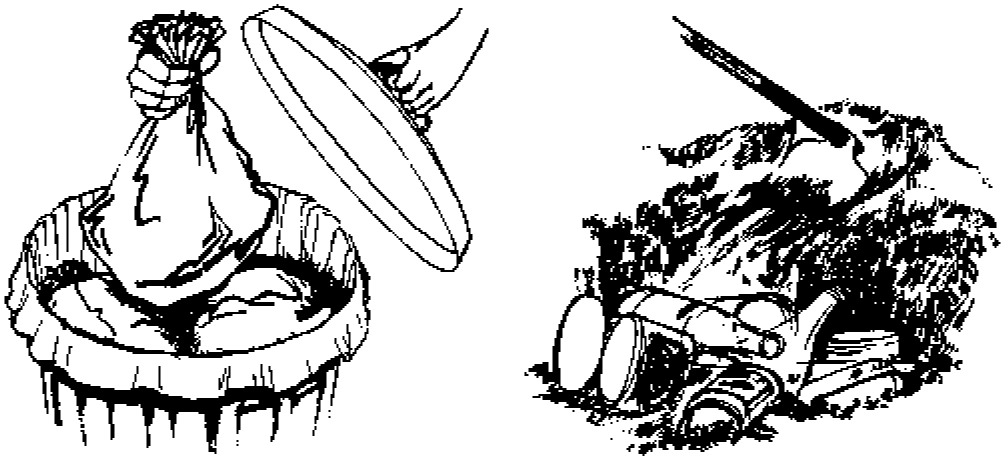


Fig. 1.108. Dispose of rubbish safely through the organized collection system or by burying it.

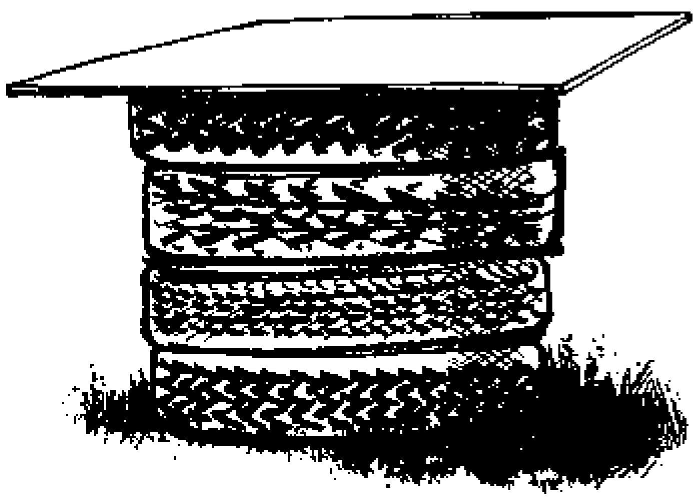


Fig. 1.109. Store tyres under a cover.

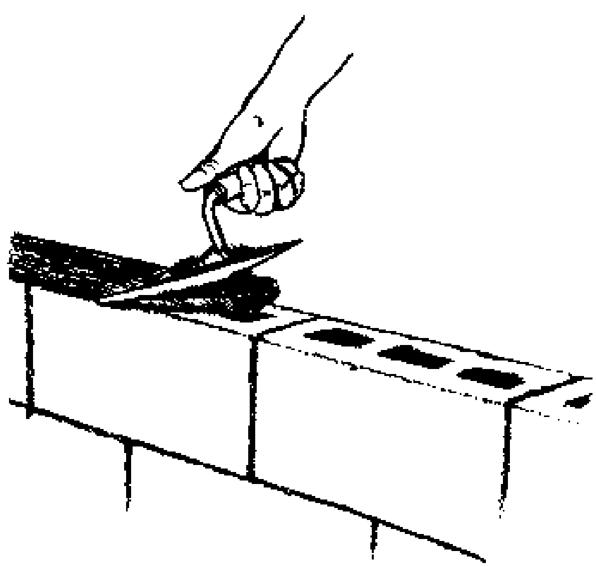


Fig. 1.110. Fill holes in construction blocks with cement or sand.

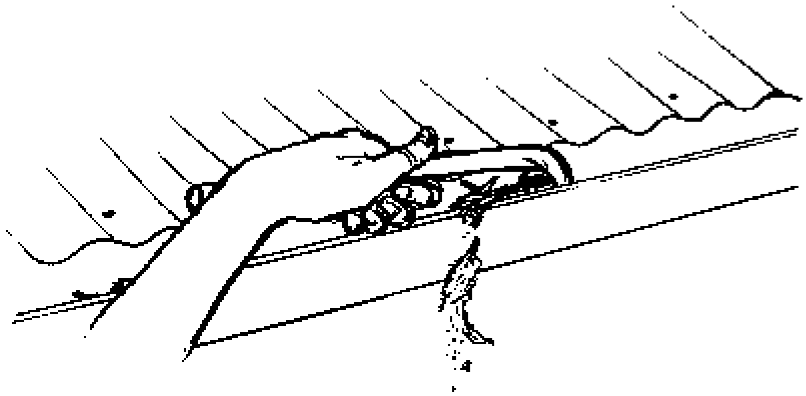


Fig. 1.111. Clean gutters regularly.

Fig. 1.112. Fill tree holes with sand or concrete.

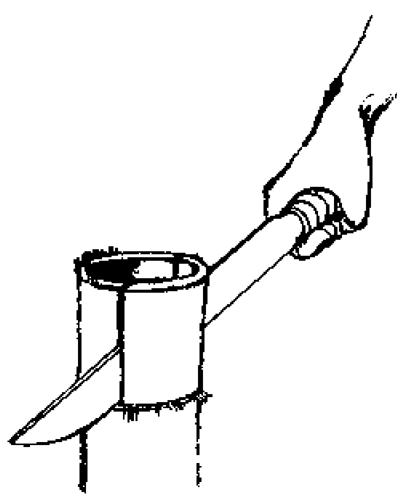


Fig. 1.113. Cut down bamboo stumps to the node.

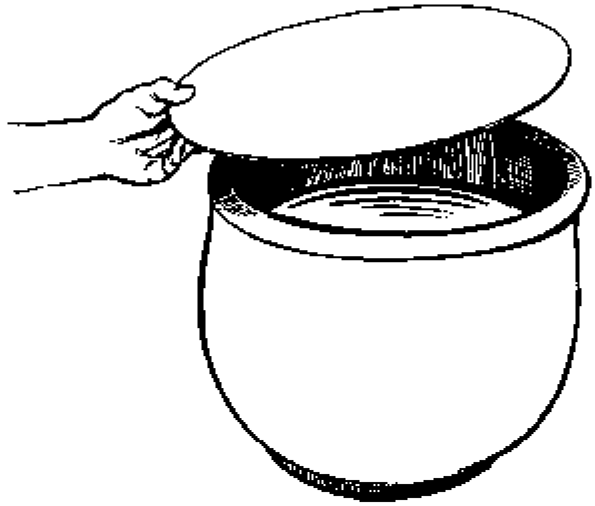


Fig. 1.114. Cover open jars with a tight-fitting lid.

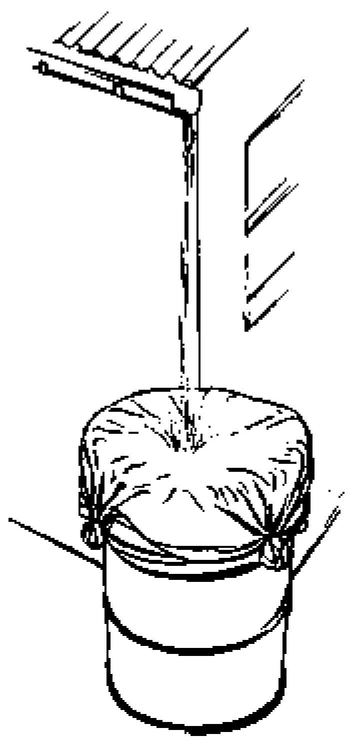


Fig. 1.115. Cover barrels and drums with cloth or netting.

Control measures

• **Small water jars** should be completely emptied about once a week and the inner surfaces scrubbed to remove mosquito eggs.

• **Open jars** can be covered with rigid lids (Fig. 1.114). This only stops mosquitos if the jars have smooth edges and the lids fit tightly.

• **Jars, drums, barrels and other containers** can be covered with cloth or netting (Fig. 1.115). Flexible lids can be made by fitting durable netting on a frame. This allows rainwater to enter.

• **Water tanks** can be made mosquito-proof with a fixed cover incorporating a sieve to allow rainwater to enter (Fig. 1.116). If a tap is attached to the bottom of the tank, the cover can be left permanently in place. Regular cleaning or changing of the sieve is necessary.

Large water tanks can be equipped with a self-cleaning wire-mesh screen cover. One model consists of stainless steel screening embedded in a cement mould (Fig. 1.117). Rainwater runs through the screening into the tank, leaving behind dirt, most of which is automatically washed off because of the slope of the screening.

This strainer has been developed in Tonga. It is not commercially available, but could be made on a large scale using a metal mould. If small numbers are needed, it would be more practical to attach the wire mesh to a base made of metal, timber or other water-resistant material.

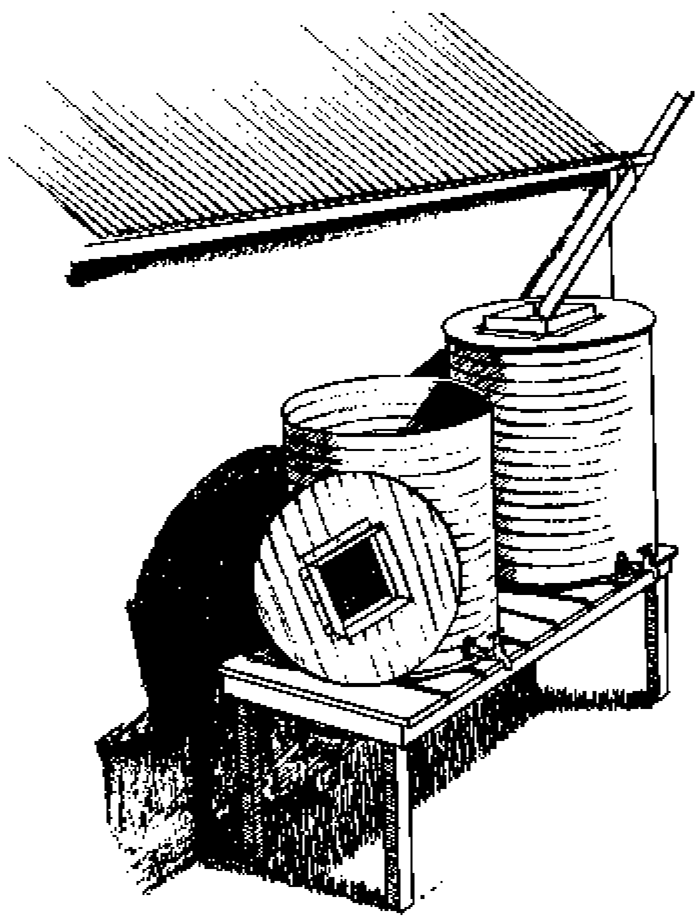


Fig. 1.116. A fixed cover incorporating a sieve.

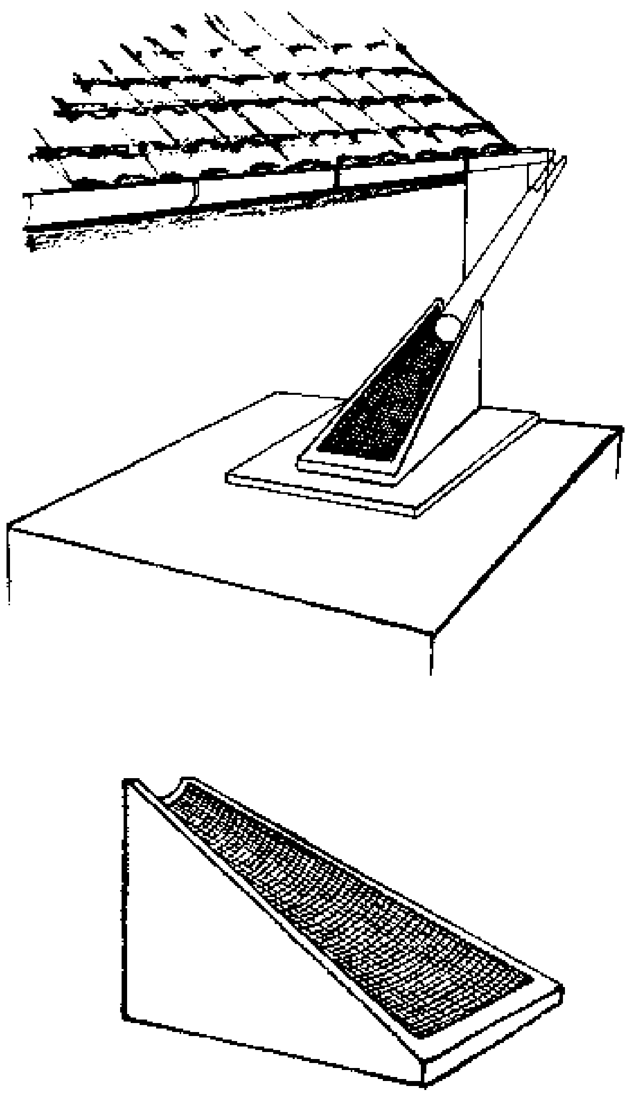


Fig. 1.117. A self-cleaning wire-mesh cover for a water tank.

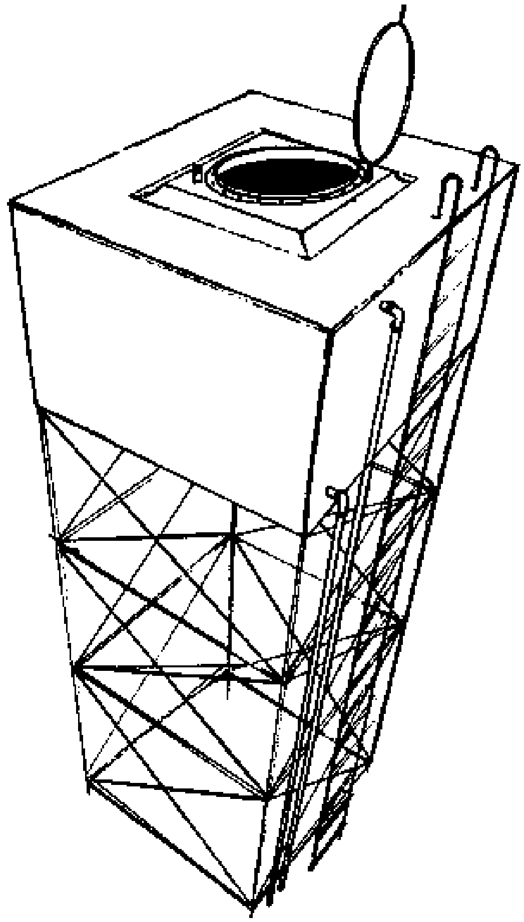


Fig. 1.118. Elevated storage tanks should have a tight-fitting lid.

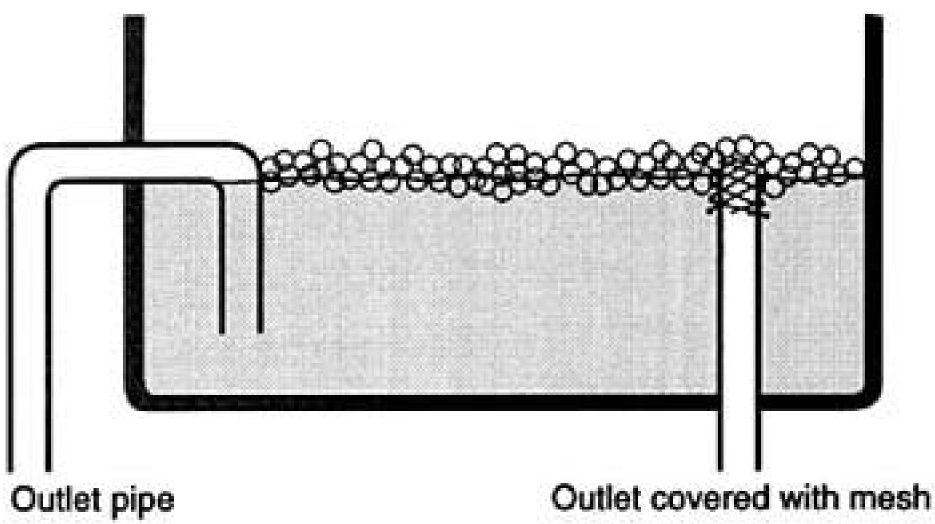


Fig. 1.119. If polystyrene beads are used in water storage tanks, the outlet must be protected from blockage (© WHO).

Elevated or roof-top water storage tanks, to which water is pumped from below, do not have an inlet for rainwater, but often have an opening to allow for cleaning and inspection. This opening should have a tight-fitting lid (Fig. 1.118).

• **A layer of polystyrene beads** (p. 119), completely covering the water surface, stops mosquitos from breeding and reduces evaporation. The beads can be applied to the water in tanks that have an outlet at the bottom. If the water level in the tank falls to the level of the outlet, there is a risk of the beads blocking the pipe; to prevent this, the outlet should be screened with durable mesh or fitted with a downward bent pipe (Fig. 1.119). The latter device is commonly used to prevent floating dirt from being drawn from a tank.

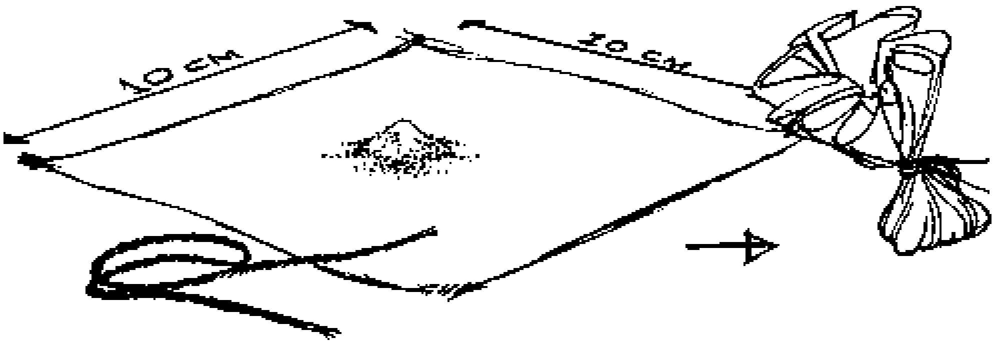


Fig. 1.120. Temephos sand granules can be wrapped in permeable cloth for use in water containers.

Tanks should be covered to prevent birds, squirrels or lizards from trying to walk on the layer of beads.

• **Temephos** (p. 132) is a relatively safe and effective insecticide that can be used in drinking-water at a dosage rate of not more than 1 mg/litre. At the recommended dosage it does not give a detectable taste to drinking-water and is harmless to humans, other mammals and fish. It is available as sand granules impregnated with 1% insecticide. In a water tank, the sand granules slowly give off the insecticide for about 4 - 6 weeks. Temephos granules are cheaper and more widely available than methoprene or *B.t*. H-14.

Granules can be wrapped in permeable cloth so that the packets can be removed easily when a domestic water pot is emptied for cleaning and then replaced when it is refilled (Fig. 1.120).

• **Methoprene** (p. 135) is safe for use in drinking-water, but is more expensive than temephos. Slow-release briquettes may last up to five months.

• ***Bacillus thuringiensis* H-14** (*B.t.* H-14) (p. 136) is tasteless and safe for use in drinking-water. It is available in granules and tablets (briquettes) which float on the surface and slowly release the larvicide. Briquettes may last about four weeks in a drinking-water tank.

• **Larvivorous fish**: some fish species that feed on mosquito larvae can be used in large water storage containers that are located in shade, so that there are no large fluctuations in temperature. Some light and a minimum amount of food are required.

Suitable fish species need to be able to survive long periods with little food and to tolerate temperature fluctuations. Fish should be available to re-stock water tanks. The mosquito fish (*Gambusia affinis*) and the guppy (*Poecilia reticulata*) are suitable because they are easy to rear in large quantities.

In China, good results have been obtained with the Chinese catfish (*Clarias fuscus*), one of which is sufficient in each domestic water pot (20 - 100 litres). The species survives for long periods. Measures may have to be taken to prevent them from jumping out of the container. In Somalia, a tilapia species (*Oreochromis spiluris spiluris*) has been used with success in underground water tanks; one fish is sufficient for 3 m^3 (*133*, *148*).

Wells and pools

In many tropical countries, wells and pools in rural and suburban areas with relatively clean water are used as breeding sites by anopheline mosquitos. Larvivorous fish (p. 123) or larvicides (p. 128) such as temephos, methoprene and *Bacillus thuringiensis* H-14 (p. 136) can be applied in wells used for drinking-water.

Many wells have been abandoned following the installation of piped water supplies. Filling them would be an effective solution. If wells have to remain available for possible reuse the introduction of larvivorous fish could also be considered. In places not subject to flooding, an effective and long-lasting solution is the application of a layer of polystyrene beads (p. 146).

Small pools of clean water are often found on construction sites and in the basements of buildings. They should be filled up or drained. In some cases larvivorous fish (p. 123) or larvicides (p. 128) such as oil are appropriate. Pools of relatively clean water are often formed near standpipes that do not have a proper drainage system, such as a gutter or a soakaway pit.

Breeding sites with polluted water

Culex quinquefasciatus, the vector of urban filariasis in some areas, breeds in on-site sanitation systems such as wet pit latrines, septic tanks, cesspits, cesspools, drains and canals containing stagnant water polluted with organic waste. They also breed in polluted water associated with home industries, for example in coconut husk pits. Other breeding sites are pools and disused wells used for dumping garbage. *Culex gelidus*, an important vector of Japanese encephalitis in south-east Asia, also breeds in polluted water. Pit latrines are the main breeding sites of blowflies (*Chrysomyia*), which are sometimes present in large numbers and may carry disease agents from faeces to food.

Pit latrines

Pit latrines, used for the disposal of human excreta, basically consist of a hole in the ground covered with a floor with a hole and surrounded by walls to provide privacy. The pits are normally dry in areas with dry porous soil. Only flies breed in dry pits. However, in areas with a high water table the pits contain water and often produce thousands of *Culex quinquefasciatus*. The improvement of sanitation leads ultimately to the development of water-borne systems whereby excreta are flushed through a short pipe to a septic tank or sewerage system.

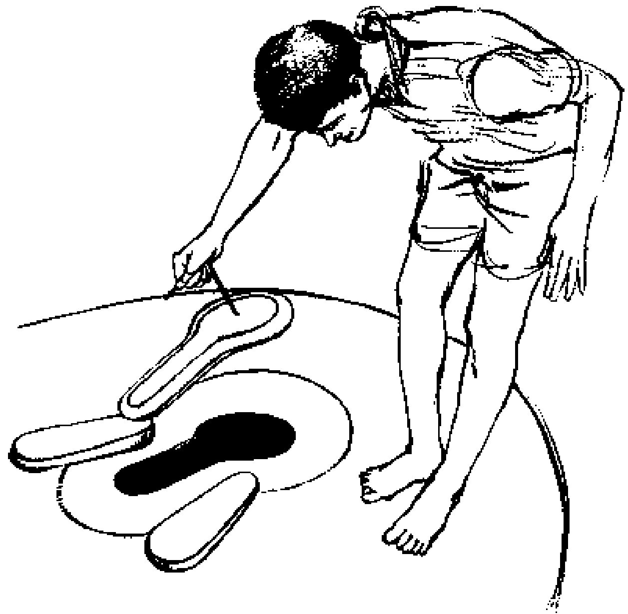


Fig. 1.121. Mosquito-proof lid for a pit latrine.

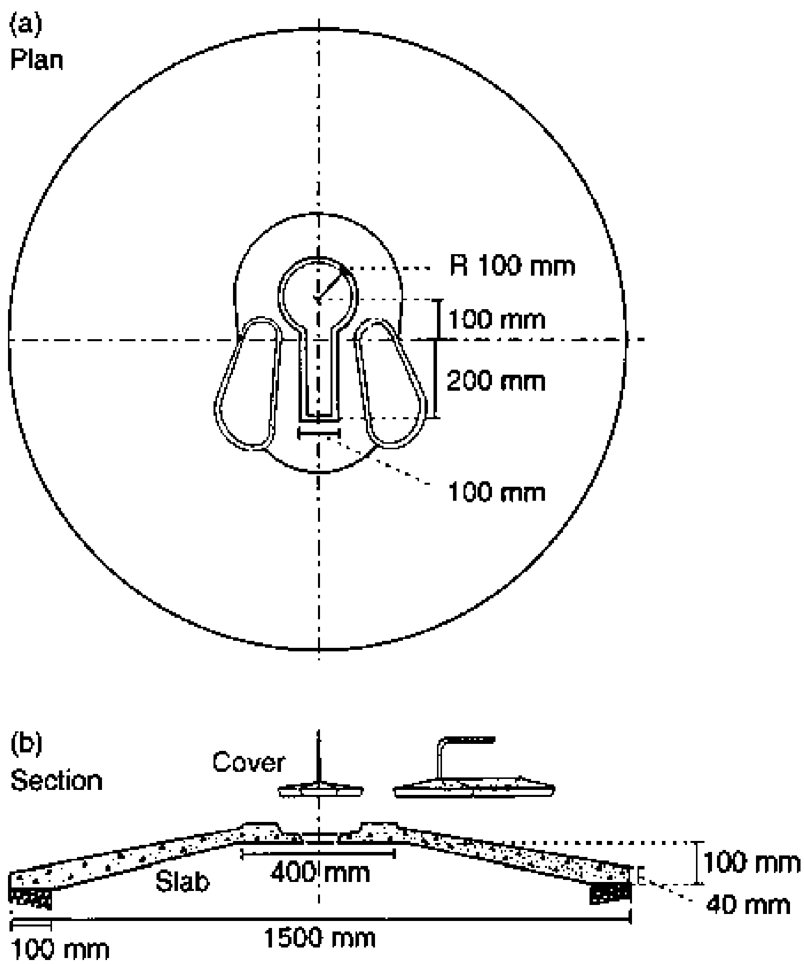


Fig. 1.122. Mosquito-proof lid for a pit latrine: (a) plan and (b) section with dimensions in millimetres. Reproduced from reference *169* with permission. Copyright John Wiley & Sons Limited.

Control measures

Improved design

Insect-proof covers prevent insects from entering or leaving pits (*135*). Lids of wood or metal do not fit tightly enough to be mosquito-proof. However, lids made of concrete can be cast in the holes in which they are to fit (Figs. 1.121 and 1.122).

Possible disadvantages

- The lid is relatively heavy, so it is difficult for children to lift.
- The edges of the lid are easily damaged, leading to loss of insect- and odour-proofing.
- Insects may enter and leave and odours may escape when the lid is lifted.
- The cost is high.

Pour-flush latrine with water seal (*135*). As for flush toilets, pit latrines can be provided with an S-bend water seal to prevent entry or exit of insects and the escape of odours (Fig. 1.123). Latrine slabs incorporating a water seal are widely available in Asian countries. The system has to be flushed with at least one litre of water and works best where people are accustomed to taking water with them to the toilet for washing. To avoid blockages and damage to the seal, solid objects should not be deposited in the latrine.

Ventilated improved pit latrine (*135*, *170 - 175*). A ventilated pit latrine has a ventilation pipe fitted which draws away odours when an air current blows across the top of the pipe. Fresh air is sucked into the pit through the squat hole in the slab covering the pit.

The inside of a latrine building with a roof is relatively dark. Blowflies emerging in the pit are attracted up the vent pipe because it is better illuminated than the squat hole. This method is partly effective against *Culex*. Because the top of the pipe is covered with flyproof netting, insects are unable to escape and eventually die.

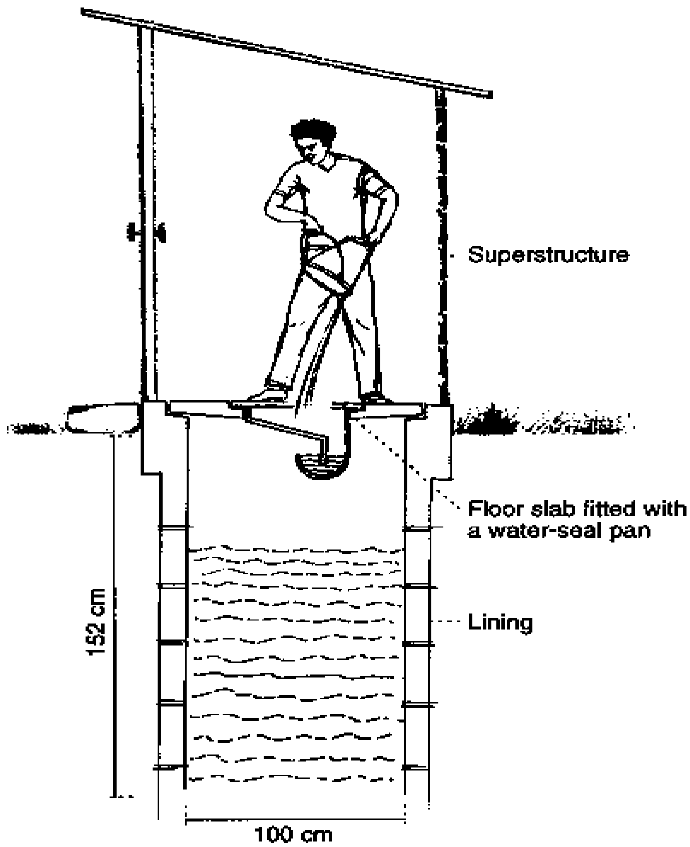


Fig. 1.123. A pit latrine incorporating a pourflush system for insect- and odour-proofing.

For proper functioning it is essential that it is dark inside the latrine building. In rectangular structures, which have a door in one wall, care has to be taken to keep it properly closed, but there should be a gap, usually above the door, to allow air to enter. An open door reduces the effectiveness of the system by letting in daylight. Permanently dark conditions are ensured by building a doorless structure with a spiral ground plan (Figs. 1.124 and 1.125).

Application of expanded polystyrene beads

Polystyrene beads poured on to the water in a pit form a floating layer on the water surface. A complete layer 1 - 2 cm thick is sufficient to prevent mosquito breeding (p. 119). An additional advantage is the suppression of the odour that emerges from the pit. After faeces have dropped through it, the layer of beads reforms immediately. If a pit dries out the beads are buried under faeces. However, because of their buoyancy, the beads return to the surface when water enters the pit. The beads will last for several years provided they are not swept away by flooding.

Application of larvicides

Oil (*156*), chemical larvicides such as fenthion and chlorpyrifos, and the bacterial larvicide *B. sphaericus* can be used to control mosquito larvae in pit latrines(p. 128). In liquid form they can simply be poured into the pits, but a better distribution over the surface is obtained by spraying. Larvicides can be applied quickly and have an immediate effect. Their main disadvantage is the need for repeated applications, which in the long term may make this method costly. Oil and most chemical larvicides remain effective for only a few weeks at most. *B. sphaericus* may remain active for up to eight weeks after application, especially at high dosages.

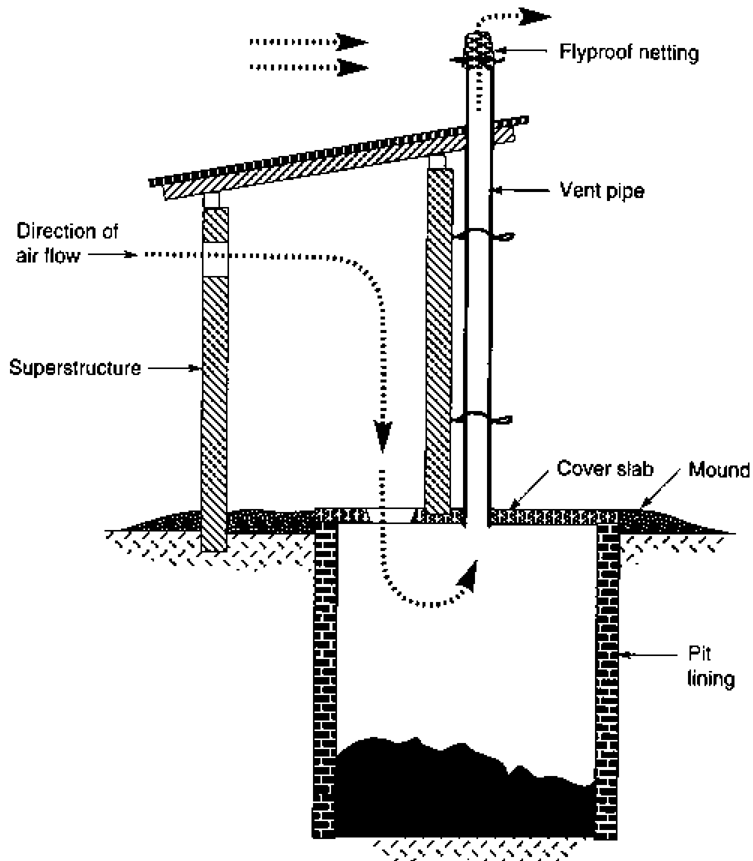


Fig. 1.124. Flow of air in a ventilated improved pit latrine (© WHO).

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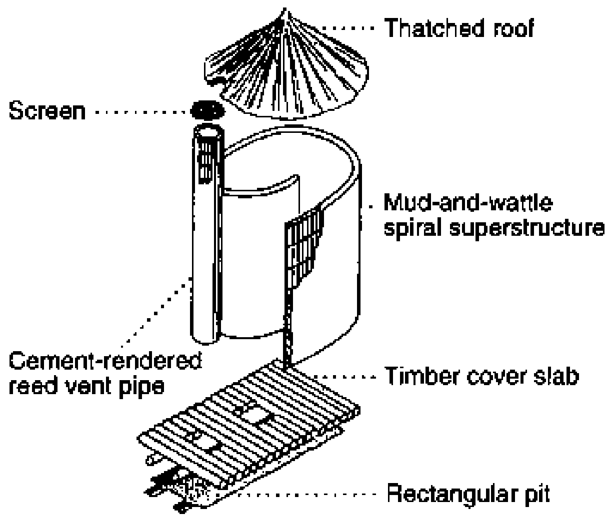

Fig. 1.125. Components of a ventilated improved pit latrine with mud-and-wattle walls and a thatched roof (*176*).

Oil has the advantage that it is widely available. Small quantities of waste oil may be obtained free of charge and are sufficient for the treatment of a latrine. Oil kills mosquito larvae only if the surface area is completely covered. On heavily polluted surfaces, however, oil does not always spread well and may be quickly destroyed.

The chemical larvicides have to be applied in higher dosages than are needed for the treatment of unpolluted water. Compounds other than fenthion and chlorpyrifos may be used if available. Larvicides should remain effective for at least a few weeks.

Septic tanks

In areas without a piped water-borne sewerage system, septic tanks are commonly used for the disposal of sewage. The watertight settling tanks receive wastes carried by water flushing down short sewers. Inside the tanks the waste separates into liquid and solid matter, the latter having to be removed at intervals. The liquid effluent may flow out of the tank through an outlet and is usually disposed of in a soakaway pit or led into a drain. The overflow sometimes forms a puddle in which mosquitos can breed. The tanks are inconspicuous but very important breeding places for *Culex* mosquitos. *Aedes* mosquitos may also be found in septic tanks. The mosquitos enter the tanks through the ventilation pipes and the water outlets (Fig. 1.126). Cracks or other openings in covers are commonly formed when tanks are opened for desludging and periodical inspections; these should be sealed immediately.

Control measures

- Cover the ventilation pipe with aluminium or stainless steel mesh screening.

- Ensure that the cover is effectively sealed; a practical solution is to cover it with sand; large gaps can be filled with foam rubber.

- A soakaway pit (see below) should be installed if excess water is periodically discharged from the tank.

• Close the outlet with material that can easily be removed.

• Apply oil, chemical larvicide or polystyrene beads if the above measures are not possible (see section on wet pit latrines). If polystyrene beads are used the outlet should be screened to prevent them from being flushed out.

Soakaway pits

In many rapidly expanding urban areas, there are few facilities for the disposal of wastewater. Under such conditions, householders may dig pits on or near their premises for the disposal of effluents. Water in soakaway pits tends to stagnate and can become a favourable breeding place for *Culex* and, less commonly, *Aedes*.

Control measures

• Fill the pit with small stones (Fig. 1.127).

• If the pit does not overflow regularly apply polystyrene beads (p. 119).

• Apply oil or chemical larvicides (p. 128) to the surface to obtain immediate short-term protection.

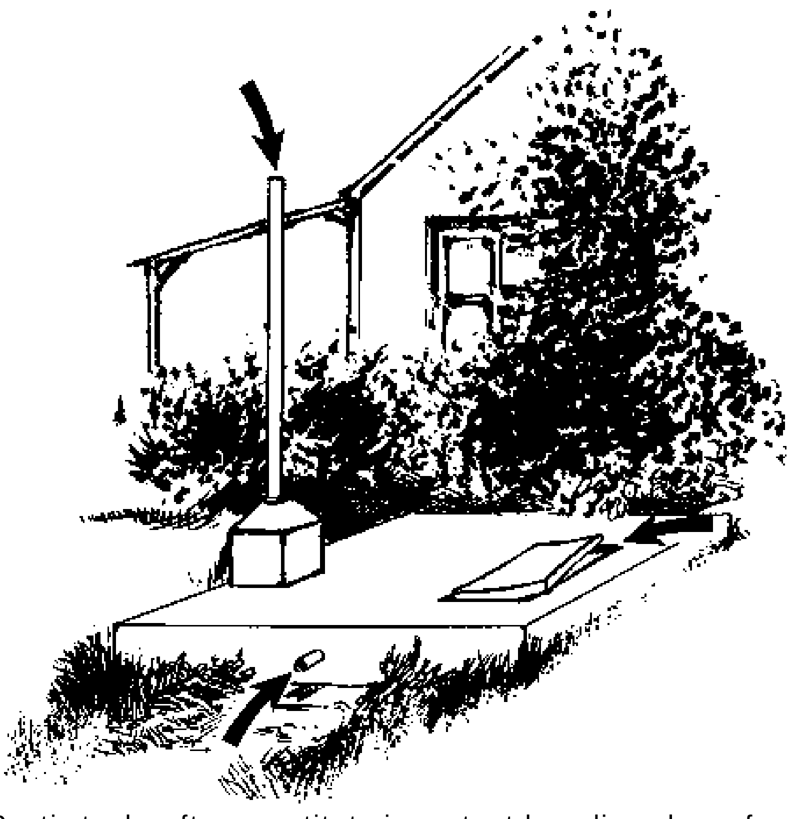

Fig. 1.126. Septic tanks often constitute important breeding places for *Culex*, which enter and leave through the ventilation pipe, the overflow outlet and improperly closed openings.

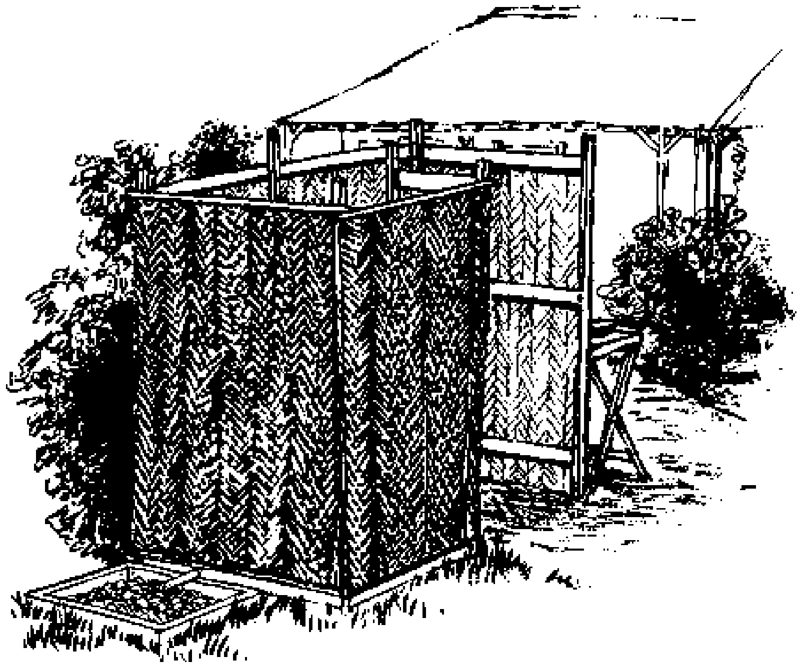

Fig. 1.127. A soakaway pit that collects run-off water used for washing and bathing can be filled with small stones to prevent mosquitos from breeding.

Drainage systems

Urban areas generally have two drainage systems, one for the disposal of sullage (washing) water and sewage and the other for the drainage of rainwater. Rainwater is often drained through a surface drainage system while sewage is disposed of via either an underground or a surface drainage system, the latter often merging with the rainwater drainage system. Underground systems may seem the best because they are not easily accessible to mosquitos. However, lids on the inspection sites are not always properly closed and when problems arise they are difficult to solve. The underground system may become blocked, overflow and form puddles in which mosquitos can breed. The surface drains often replace the underground system when it becomes clogged.

The surface drains should have a gradual slope along their course to enable a sufficiently rapid flow of water to prevent mosquito breeding and blockages. Once blockages start to form, the water flow is retarded and complete blockage of the drains becomes likely. Together with the dumping of garbage in drains this creates favourable conditions for breeding by *Culex* and other mosquitos. If surface drains are partly covered, inspection, cleaning and maintenance are made more difficult.

Control measures

- Make sure that inspection openings of underground drains are properly closed.

- Ensure that the system is properly maintained and repairs are carried out promptly.

- Remove dirt, debris and other obstacles in the system to allow the water to flow freely (Fig. 1.128).

• Flush the drains periodically with clean water to remove dirt and debris and destroy mosquito breeding sites; this may be practicable in areas where water is abundant (e.g. by the sea).

• For an immediate short-term solution, apply oil or chemical larvicide (p. 128) to the places where larvae are observed.

Fig. 1.128. Dirt, debris and other obstacles in drainage systems should be removed to allow the water to flow freely.

Habitats in the field

Several species of disease-carrying mosquito breed away from the domestic environment, both in naturally occurring habitats, such as swamps, rivers, creeks, lakes and ponds, and in man-made habitats, such as reservoirs, irrigation systems, irrigated fields and borrow-pits. Breeding in man-made habitats can sometimes be prevented by proper planning and design to make them unsuitable as breeding sites or to facilitate the implementation of control measures.

Effective larval control in rural areas requires a thorough understanding of the behaviour and breeding sites of the target species. Control activities should be planned, designed and supervised by experts in vector control so as to avoid mistakes and the waste of valuable resources. On some sites, such as swamps, rivers and lakes, these activities may have to be carried out by specialized teams. However, for the smaller breeding sites the involvement of local health services, communities, farmers and others is often essential to secure control.

The most important targets of control methods are the malaria-carrying *Anoph-eles* mosquitos, which breed in a wide variety of habitats. Other targets are the *Mansonia* vectors of brugian filariasis which breed in swamps and pools, and the *Culex* vectors of Japanese encephalitis which breed mainly in rice fields and adjacent ditches.

Larval control measures usually have to be carried out over an area with a radius of 1.5 - 2 km from human habitations, the maximum flight range for most species of mosquito. In some areas the transmission of disease and the breeding of mosquitos are largely limited to well-defined periods of the year, during which control efforts are particularly important.

Swamps and marshes

In many countries, swamps have become less important as breeding sites for mosquito vectors of disease as a result of land reclamation associated with urban and rural development.

Control measures

Source reduction

If swamps prove to be breeding sites they may be filled if relatively small and close to towns. Filling is usually uneconomic if swamps are extensive and there are no large settlements within flight range. Breeding sites can be drained (p. 114) and dried out by reducing the amount of water going into swamps or by increasing the rate of drainage. The input of water can in some cases be reduced by digging interceptor drains around the outer edges of swamps, usually at the foot of a hill (Fig. 1.129). In other cases drainage ditches may be made across swamps. Sometimes a dam can be constructed at the lower end of a swamp, causing conversion of the swamp into a deep lake in which larvivorous fish can be kept. Shallow marshlands and plots of land with a high water table can be dried out by planting eucalyptus trees (p. 119).

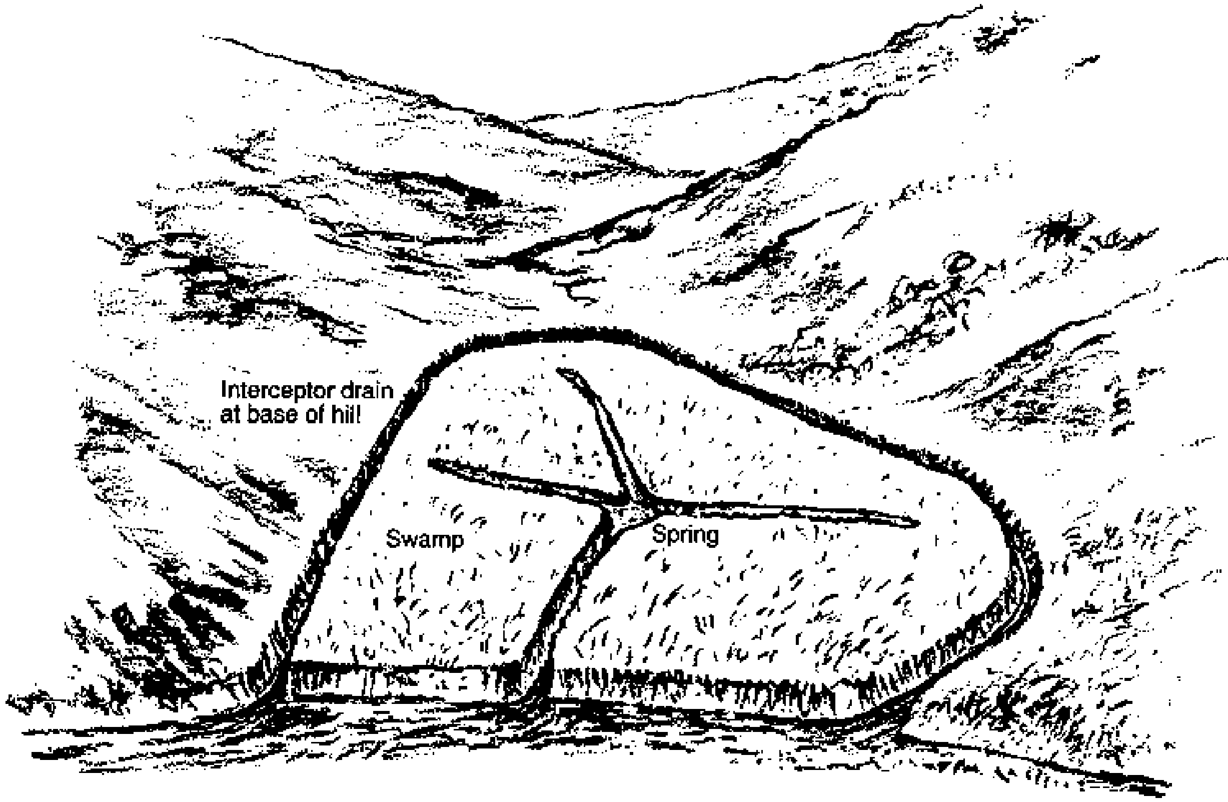

Fig. 1.129. Drainage of a swamp with interceptor drains (*131*).

Larvicides

Larvicides are sometimes used in emergency situations. Granular formulations are most suitable, because they are easy to disperse and fall through vegetation into the water. Ultra-low-volume sprays (p. 132) may be applied by hand- or vehicle-carried mistblowers or by aircraft, the latter being used for quick action in extensive areas that are difficult to enter by other means. If fogging is conducted at the upwind side of a swamp, the wind will carry the particles into it over a considerable distance. Seasonal marshes that become submerged during and after the wet season may be treated with slow-release formulations (briquettes) of insect growth regulators (p. 134).

Lakes and reservoirs

If breeding occurs in lakes and reservoirs it normally takes place along the margins in shallow places protected by vegetation from fish, waves and excessive sunlight.

Control measures

Water-level fluctuation

Sometimes it is possible to construct a dam with a sluice at the outlet of a lake, as is usual in man-made reservoirs. This allows the water level to be raised and lowered (p. 121) at intervals. Keeping the water at a high level kills terrestrial vegetation on the shore. The level is kept as low as possible during the mosquito breeding season so as to strand mosquito larvae and floating objects along the margins and to inhibit the growth of aquatic plants. This leaves a clean margin around the lake which does not offer any suitable breeding sites. The water level is raised and lowered at intervals of 7 - 10 days, less than the time needed for the development of the aquatic stages of the mosquito. Where needed this measure can be supplemented by the removal of accumulations of floating debris and vegetation.

Coastal swamps and lagoons

Swamps and pools often occur behind coastlines, which are filled with seawater during spring tides but which are not subject to daily tidal action. As with freshwater swamps they can be filled or drained if this is economically feasible. Alternatively, automatic sluice gates can be constructed which let water out at low tide but prevent the influx of seawater at high tide. A simpler solution is to connect swamps and pools to the sea by ditches or culverts. This provides tidal action and the alternating presence of fresh and salt water, which prevents the development of suitable breeding habitats for most mosquito species (other than *Anopheles melas* in West Africa) (Fig. 1.130).

To control pest mosquitos (especially *Aedes* species) breeding in tidal salt marshes, granular insecticides are sometimes used; they release insecticide only after flooding, which coincides with the hatching of the eggs.

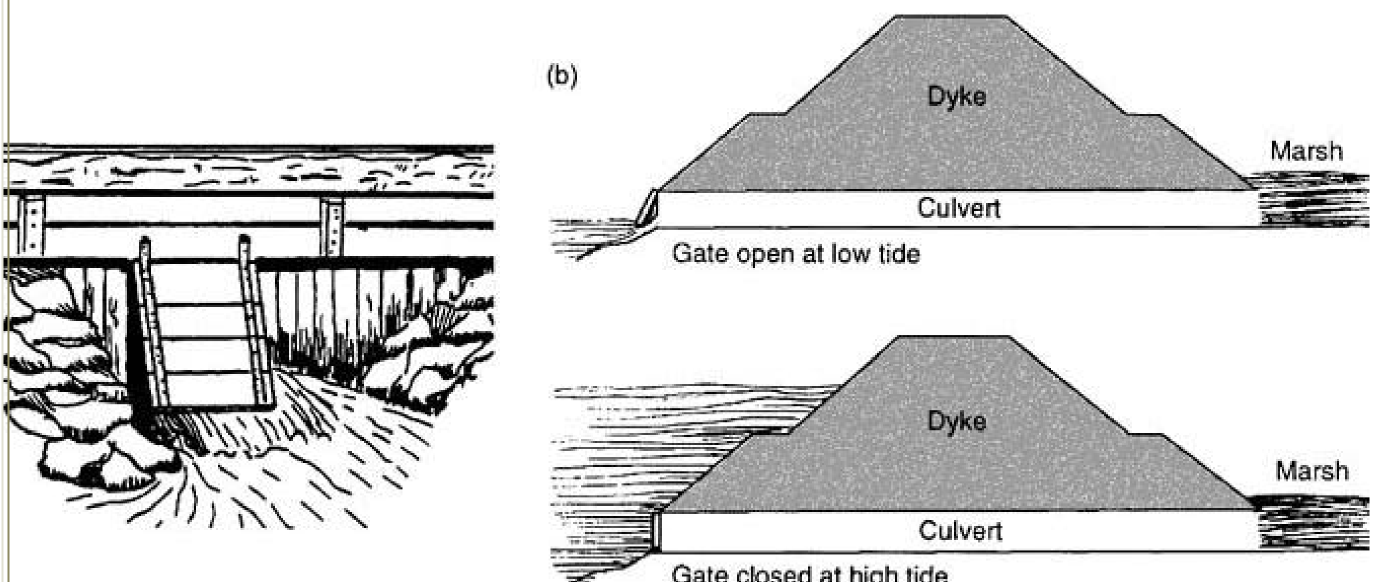

Fig. 1.130. Sluice gates can allow swamps to drain into the sea, while preventing influx of seawater at high tide (*133*).

Larvicides

Larvicides can be applied from a boat with a spraying machine.

Rivers and creeks

Mosquitos breed in quiet places close to the banks of rivers and creeks where there is protection from currents by obstacles, protruding roots, plants and so on. Effective control of larvae is generally difficult because of the large areas to be covered. Careful study is required to find out the exact location of the breeding sites.

Fig. 1.131. During the dry season mosquitos may breed in stagnant pools in river beds.

Control measures

Source reduction

Breeding sites may be reduced in some cases by removing obstructions and vegetation from the edges of the rivers and smoothing and increasing the gradients of the banks to increase the water velocity. In the dry season, pools may form in river beds (Fig. 1.131). If breeding occurs in such pools they can be drained into the main stream. Some smaller pools may be filled up.

Larvicides

Pools in river beds may be treated with larvicides (p. 128) that are not toxic to fish, or to other animals or humans using the water for drinking. In pools that dry out quickly, one application is sufficient. In pools that are likely to exist for a month or longer it is advisable to apply a slow-release formulation, e.g. temephos sand granules, to avoid the need for frequent reapplication.

Small creeks

Some success has been obtained in the control of *Anopheles maculatus*, a vector of malaria in parts of south-east Asia, which breeds in forest creeks in hilly areas. The breeding of this mosquito can sometimes be prevented by spraying quiet places and pools in the creeks with larvicidal oil or a chemical larvicide that does not harm fish (p. 128). In a few places small dams have been built upstream of breeding sites. The water collected behind the dams is released at intervals to flush out larvae (p. 121) and destroy breeding habitats. The dams, which are either hand-operated or automatic, provide a long-lasting solution without high recurrent costs.

Ponds

Permanent ponds containing unpolluted water are commonly used for breeding by *Anopheles* and *Mansonia*. *Mansonia* occurs only in the presence of aquatic vegetation to which the larvae and pupae can attach.

Control measures

Filling

Earth for filling can sometimes be obtained from a deep pond to be used for the cultivation of fish (p. 114). In most cases, however, filling is too costly and may even be unacceptable where ponds are used as water supplies.

Larvivorous fish

Larvivorous fish are effective in long-lasting control of mosquito larvae in ponds (Fig. 1.132; p. 123). The shorelines of ponds should be made steep and water plants along the edge should be removed to enable the fish to reach the larvae (p. 122). In addition, carp or gouramis can be introduced to eat the vegetation. It may be possible to deepen one end of the pond so that the fish can survive if the water level falls in the dry season.

Removal of water plants

The removal of water plants renders ponds temporarily unsuitable for breeding by *Mansonia* (Fig. 1.132; p. 122) (*177*, *178*).

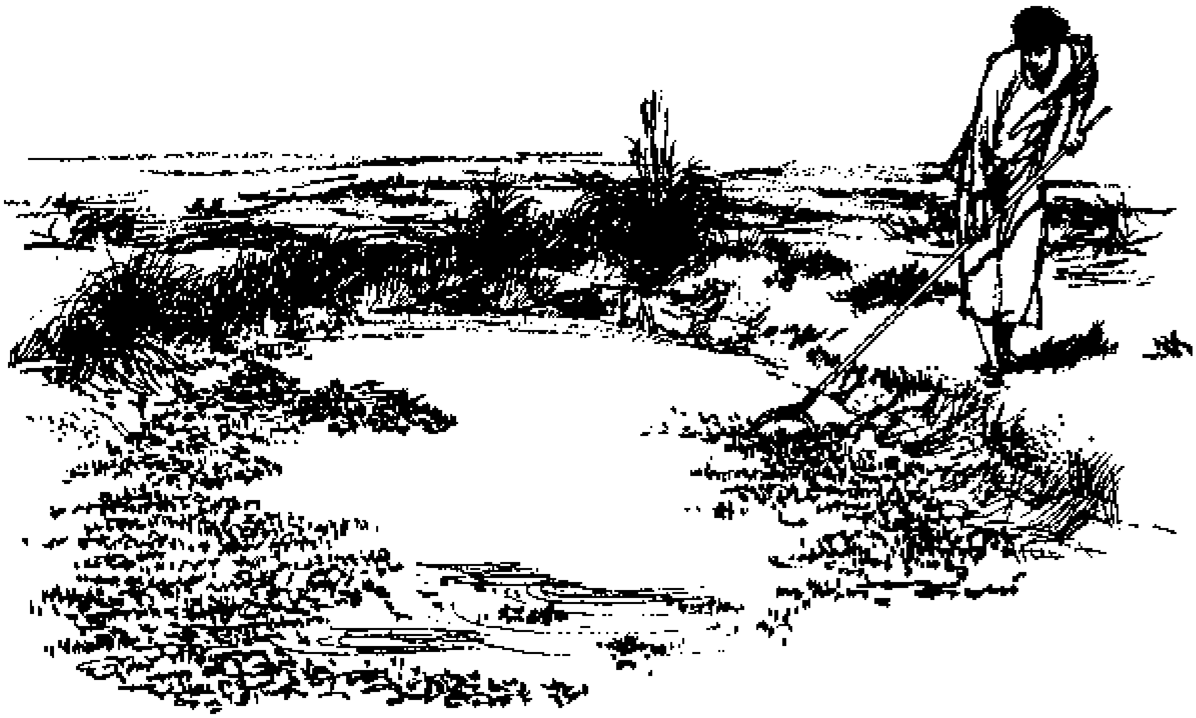

Fig. 1.132. Ponds can be rendered unsuitable for mosquito larvae by removing water plants.

Removal of vegetation along margins and steepening shorelines

These measures reduce the breeding of most mosquito species temporarily by taking away protective cover and removing shallows (Fig. 1.132; p. 122).

Oil and chemical larvicides

These can be applied to the water surface for a quick effect of short duration (p. 128). Slow-release formulations, such as briquettes of methoprene (p. 135) or *B.t*. H-14 (p. 136), last a month or longer. Care should be taken not to use a compound that could kill naturally occurring predator insects and fish. Herbicides are sometimes used to destroy the plants to which *Mansonia* larvae attach themselves.

Borrow-pits

Soil is used in rural areas of many countries for the construction of houses and roads. It is collected from pits that are usually located outside villages. The pits may collect rainwater or seepage water and provide breeding places for a number of mosquito species. Older pits containing vegetation are usually better breeding sites than freshly dug pits.

Control measures

Filling

Soil for filling up borrow-pits can sometimes be obtained from village fish ponds that are being deepened or expanded (p. 114) (*177*, *179 - 181*). Alternatively, borrow-pits can be used for the disposal of household rubbish or industrial waste, such as sawdust and cinders (*179*). The rubbish should be covered with a layer of soil to prevent exposure of potential water containers, such as bottles and cans, or access of flies and rats to the rubbish.

Drainage

A row of borrow-pits may be drained with ditches into one single pit, so that only one wet pit remains to be dealt with.

Application of oil and larvicides

This provides a quick solution of short duration. However, slow-release briquettes of methoprene (p. 135) or *B.t.* H-14 (p. 136) last 1 - 4 months and may be sufficient to cover most of the breeding season. Once the pits dry out the briquettes stop releasing larvicide, but under favourable circumstances may be reactivated when the pits are again filled with water. If the water is used for drinking by animals or humans the larvicides should be safe for use in drinking-water; temephos, *B.t*. H-14 and methoprene could be considered.

Larvivorous fish

Because the pits are likely to dry out from time to time, larvivorous fish are usually not appropriate for the control of larvae. However, the so-called instant fish (p. 127), whose eggs can survive dry seasons and which mature in one wet season, may be suitable under such conditions (*181*).

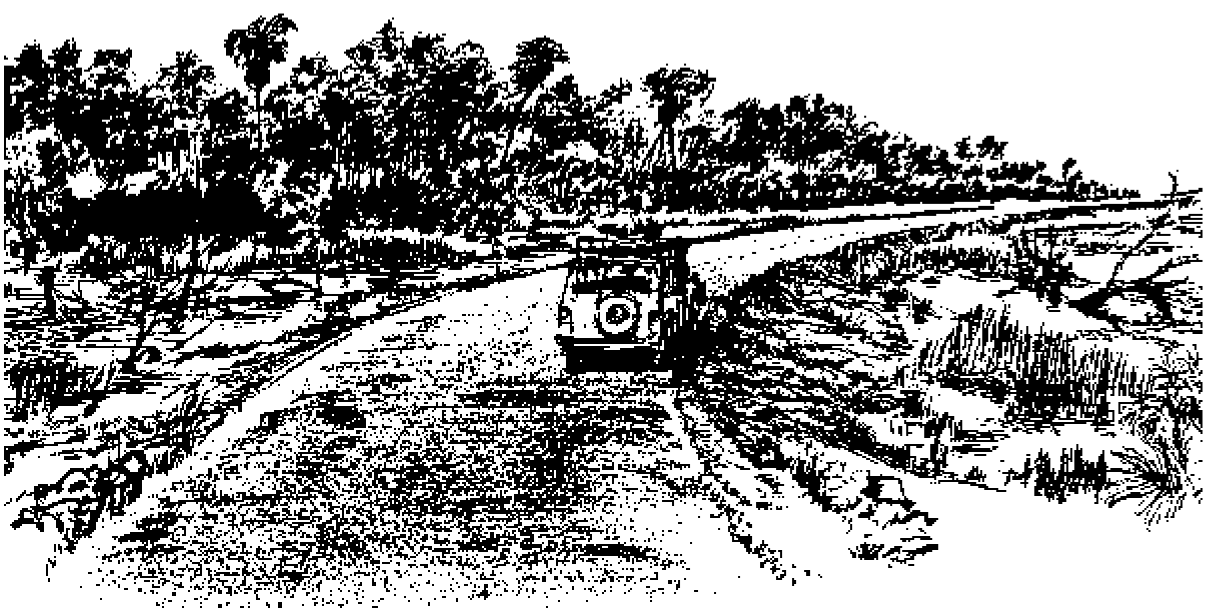

Fig. 1.133. Road construction often causes blocking of streams, resulting in the formation of bodies of stagnant water alongside the road.

Accumulations of water near roads

The construction of roads on causeways often leads to the blocking of transverse streams. This prevents natural drainage of the land and may result in the formation of large ponds alongside the roads (Fig. 1.133). Water also accumulates in borrow-pits along roads that were used for the construction of the causeway. For example, the construction of highways through the Amazon forest created numerous suitable breeding sites for the malaria vector *Anopheles darlingi*.

Control measures

- Construct culverts through the causeway allowing streams to continue on their natural courses.

- Use larvivorous fish and larvicides.

Irrigation systems and irrigated fields

Wet rice cultivation (paddy rice) and other activities involving irrigation may create suitable breeding places for some *Anopheles* mosquitos that transmit malaria and for some *Culex* mosquitos, such as *Culex tritaeniorhynchus*, which transmit Japanese encephalitis in Asia.

Mosquitos often find breeding sites in or near irrigation systems that have been poorly constructed, managed and maintained (Fig. 1.134). Breeding may occur in irrigation channels and ditches between vegetation growing along the margins. Holes in the beds of channels provide breeding places when there is no water flowing through them. Leaks may provide breeding sites in puddles outside the channels. The prevention of breeding in irrigated fields is difficult because of the very large surfaces of standing water often available to mosquitos.

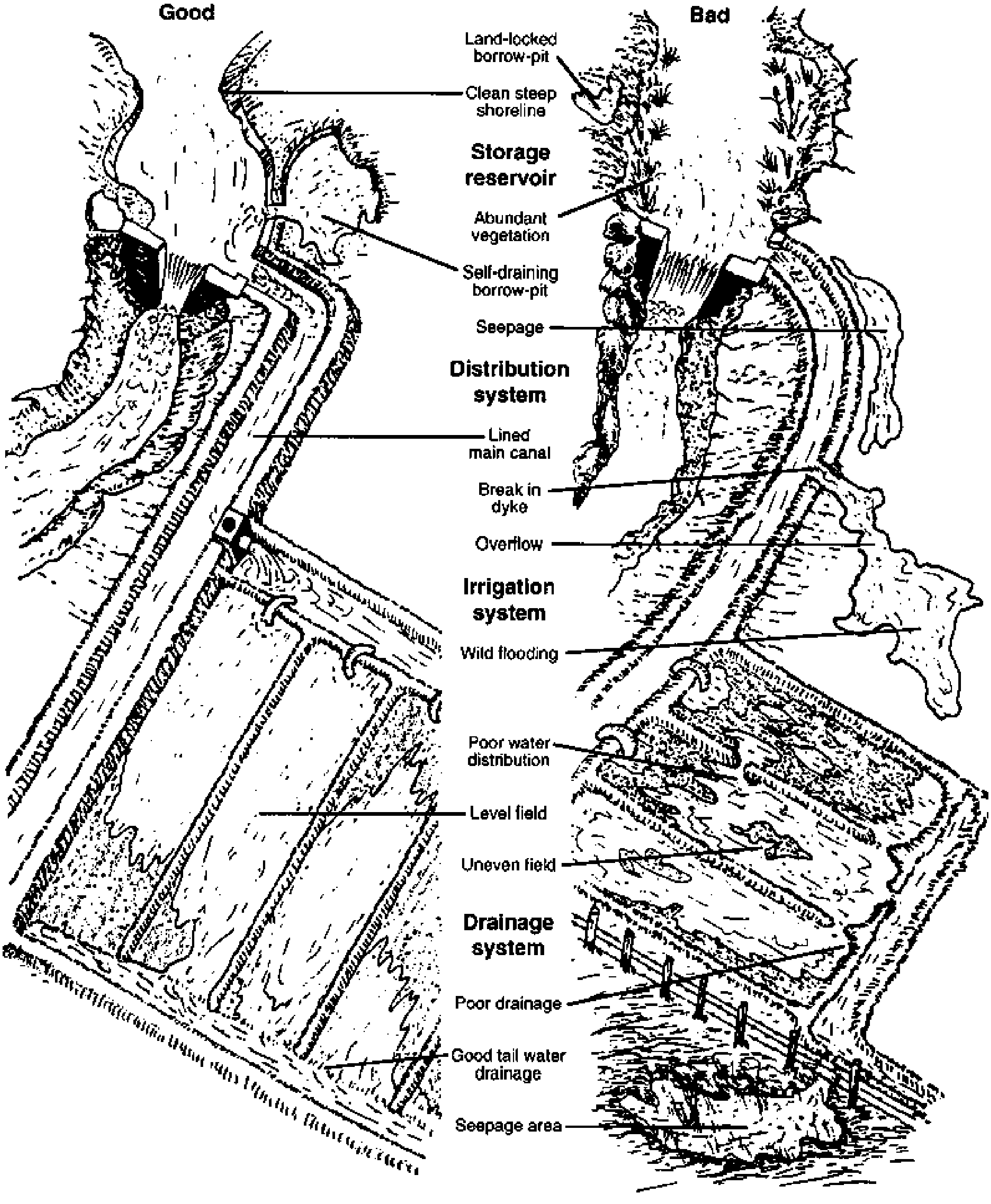

Fig. 1.134. Good and bad features often found in irrigation systems (adapted from *182*).

Control measures

Construction and maintenance

The bottoms of channels and ditches should be smooth with a gentle slope so that no stagnant water remains when they dry out. Proper maintenance should prevent leakages from sluices and the dykes and linings of fields and channels. Breeding in ditches and irrigation channels filled with water can be reduced by making the banks steeper and removing water plants. This helps to speed up the flow of water and expose the larvae to larvivorous fish and other predators.

Intermittent irrigation

During certain periods of the cropping cycle, rice plants do not have to be submerged continuously. It is therefore possible to dry the fields once a week for 2 - 3 days in order to kill larvae (*152*, *178*). This is only feasible if the farmer has sufficient water to irrigate the field again after having drained it. The fields have to be level and very well drained so that they dry out completely after the inflow of water has been stopped. In some places the rice crop may improve with this system of irrigation. The most effective periodicity of the alternating wet and dry cycles has to be determined by an expert since it depends on the type of irrigation, soil texture, variety of rice plant and other factors. Experts would also have to determine the possibility of any negative side-effects, such as an increase in floodwater mosquitos.

A problem in the application of intermittent irrigation is the need to keep fields flooded during the first 2 - 3 weeks after transplanting the rice seedlings to permit them to establish themselves. During this period, mosquitos can be controlled with one of the other methods. If larvivorous fish are used, deep pools are needed in the fields or ditches to allow the fish to survive during dry periods. Intermittent irrigation has to be used simultaneously for all rice fields over a large area throughout the entire cropping season (*152*). In some countries, the drying out of fields at intervals has been legally imposed on farmers (*154*).

Floating ferns

Free-floating water ferns (*Azolla*) can form thick layers of vegetation which completely cover large areas of water. In China and India, *Azolla* is cultivated as a fertilizer and animal feed. If a high degree of coverage of a rice field is achieved it offers the extra benefit of mosquito control (*183 - 185*). It is important to obtain good coverage before the usual peak in mosquito breeding. In many situations this is difficult to achieve because of fluctuating water levels.

Larvivorous fish

Paddy fields can be made suitable for rearing fish for food and for larval control if the dykes are made stronger and higher than usual, allowing water to be retained to the desired depth. Inlets and outlets of water should be screened with a wire grille to prevent fish from escaping. A deeper pond or trench is needed near the outlet to provide shelter for the fish when the field dries out or when the fish are not foraging in the shallow water among the rice plants. A problem that may occur is the predation of fish by birds such as herons. If insecticides of the organochlorine group, such as DDT, dieldrin or lindane are applied in rice fields to control agricultural pests, they may accumulate in the fish, rendering them unfit for human consumption. Some insecticides, especially those of the pyrethroid group, are very toxic to fish.

Keeping fish in rice fields may have a positive effect on rice production: several fish species eat the weeds that compete with rice plants; fish excrement fertilizes the soil; fish stir up the soil and improve the access of oxygen to the roots of the plants (*148*, *152*, *186 - 188*).

Some suitable fish species are:

- tilapia (*Oreochromis mossambicus*); the fingerlings (young stages) feed on mosquito larvae and grow rapidly;

- carp (*Ctenopharyngodon idella*, *Cyprinus carpio*); these eat weeds and, when small, mosquito larvae;

- guppy (*Poecilia reticulata*);

- mosquito fish (*Gambusia affinis*);

- panchax (*Aplocheilus panchax*); these are commonly found in paddy fields and ditches in south-east Asia.

Larvicides

The use of larvicides is costly, and requires special equipment and trained staff because of the large surfaces to be covered. Larvicides have been applied from fixed-wing aircraft, helicopters, and by hand with the aid of portable knapsack sprayers (p. 128). The resistance of mosquitos to insecticides is a problem in some areas. Another disadvantage is the potential harm to other organisms such as larvivorous fish and predator insects (dragonfly larvae). The application of *Bacillus thuringiensis* H-14 (p. 136) or insect growth regulators (p. 134) would avoid the problems of resistance and harmful side-effects. They have to be applied in a special formulation to prevent the particles from sinking to the bottom. The surface-feeding *Anopheles* larvae are killed only if the particles remain at the surface, where dispersion is improved by adding a spreading agent. Floating granular formulations remain on the surface and release toxic particles over a period of several weeks, but their effectiveness may be reduced if the wind blows them to one side of the field. The use of larvicidal oil also avoids the problem of resistance and usually does not harm fish, although some aquatic predator insects may be affected.

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Chapter 2 - Tsetse flies

Vectors of sleeping sickness

Tsetse flies are bloodsucking flies of the genus *Glossina*. They occur only in tropical Africa and are important as vectors of African trypanosomiasis in both humans and animals. Sleeping sickness, as it is commonly called, is generally fatal in humans if left untreated. Sleeping sickness occurs in scattered foci throughout Africa south of the Sahara. In 1996, it was estimated that between 20000 and 25000 people die from the disease annually; however, the risk of severe epidemics continues to exist.

Biology

Tsetse flies are robust, 6-15 mm in length, and can be distinguished from other biting flies by their forward-pointing mouthparts (proboscis) and characteristic wing venation (Fig. 2.1).

There are about 30 known species and subspecies of tsetse flies belonging to the genus *Glossina*. They can be divided into three distinct groups or subgenera: *Austenia* (*G. fusca* group), *Nemorhina* (*G. palpalis* group) and *Glossina* (*G. morsitans* group). Only nine species and subspecies, belonging to either the *G. palpalis* or the *G. morsitans* group, are known to transmit sleeping sickness (Table 2.1).

Life cycle

The female tsetse fly does not lay eggs but produces larvae, one at a time. The larva develops in the uterus over a period of 10 days and is then deposited fully grown on moist soil or sand in shaded places, usually under bushes, fallen logs, large stones and buttress roots. It buries itself immediately and turns into a pupa. The fly emerges 22-60 days later, depending on the temperature. Females mate only once in their life and, with optimum availability of food and breeding habitats, can produce a larva every 10 days.

Resting places

The flies pass most of their time at rest in shaded places in forested areas. The preferred sites are the lower woody parts of vegetation; many tsetse flies hide in holes in the trunks of trees and between roots (Fig. 2.2). They search for food only for very short periods during the day. The flies often rest near to food sources. Common risk areas where people are likely to be bitten by tsetse flies are:

- on forest trails;

- near water collection points in forests;

- in vegetation close to bathing and water collection sites along the banks of rivers;

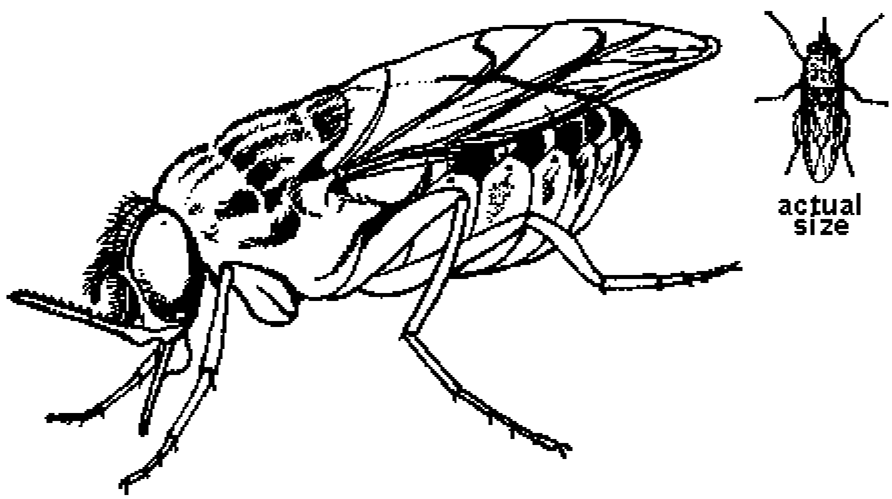

Fig. 2.1. Tsetse fly; this shows a feeding fly with a swollen abdomen (by courtesy of the Natural History Museum, London).

Table 2.1 Species and subspecies of *Glossina* known to transmit sleeping sickness

G. palpalis group (subgenus Nemorhina)	***G. morsitans group (subgenus Glossina)***
palpalis gambiense *palpalis palpalis* *tachinoides* *fuscipes fuscipes*	*morsitans centralis* *morsitans morsitans* *pallidipes*

fuscipes quanzensis *fuscipes martinii*	

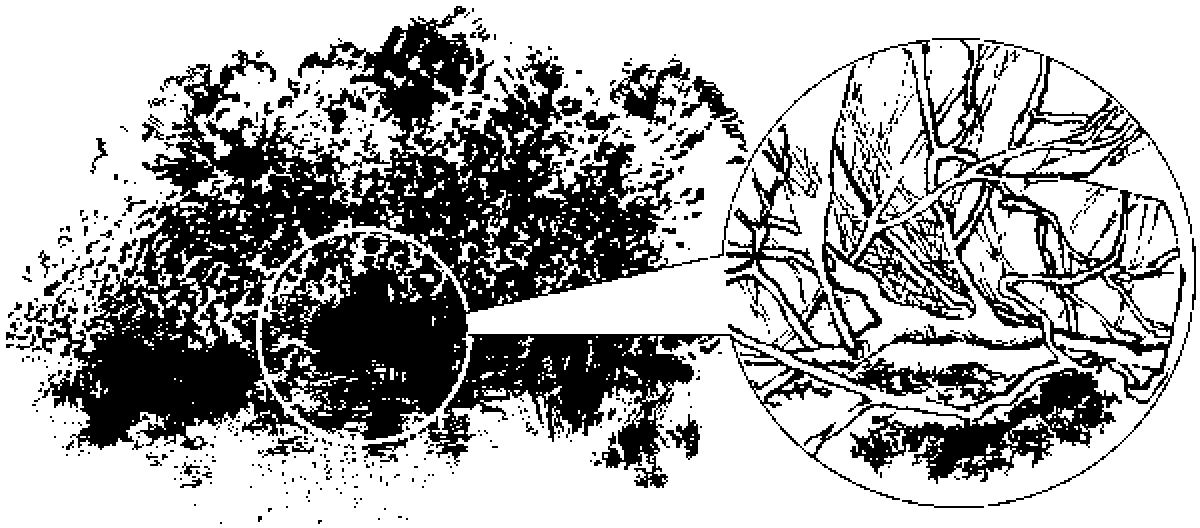

Fig. 2.2. In forested areas, tsetse flies typically rest on twigs and woody parts of vegetation close to the ground.

- in vegetation surrounding villages;
- sacred forests or forests on cemeteries;
- forest edges surrounding plantations (e.g. of coffee or cacao);
- savanna habitats (*morsitans* group).

These areas often form a boundary between two different habitats or vegetation types of which at least one is wooded. Such a combination offers the flies both safe resting places and a good view of their feeding grounds.

Food

All tsetse flies, males as well as females, feed on blood, but the species differ in their preferences for the source of blood. Most tsetse flies feed preferentially on animals and only accidentally on humans. The most dangerous species are those that are flexible in their choice and feed on any blood source that is easily available, including humans. While searching for food they are attracted by large moving objects, by strikingly blue objects (*1*), and by carbon dioxide.

Public health importance

Tsetse flies cause painful bites and, during the day, can be a nuisance where they occur in large densities.

Sleeping sickness

Two different types of human sleeping sickness are caused by different subspecies of trypanosome parasites (Fig. 2.3):

- gambiense sleeping sickness (caused by *Trypanosoma brucei gambiense*) is generally considered to be a chronic disease and is found mostly in West and Central Africa;

- rhodesiense sleeping sickness (caused by *Trypanosoma brucei rhodesiense*) is an acute disease that occurs mainly in East Africa.

In 1996 it was estimated that some 50 million people in 36 countries are at risk of acquiring sleeping sickness. However, only about 20000 new cases are reported annually. Between 2% and 3% of them die as a consequence of resistance to the drugs and secondary effects of the drugs. It is believed that many cases go unreported.

Other trypanosome species can cause diseases in wild and domestic animals, including cattle, pigs and horses.

Transmission

Tsetse flies can acquire trypanosome parasites by feeding on infected people and large domestic and wild animals. When an infected tsetse fly bites it injects the parasites into the blood. The parasites multiply and invade the body fluids and tissues.

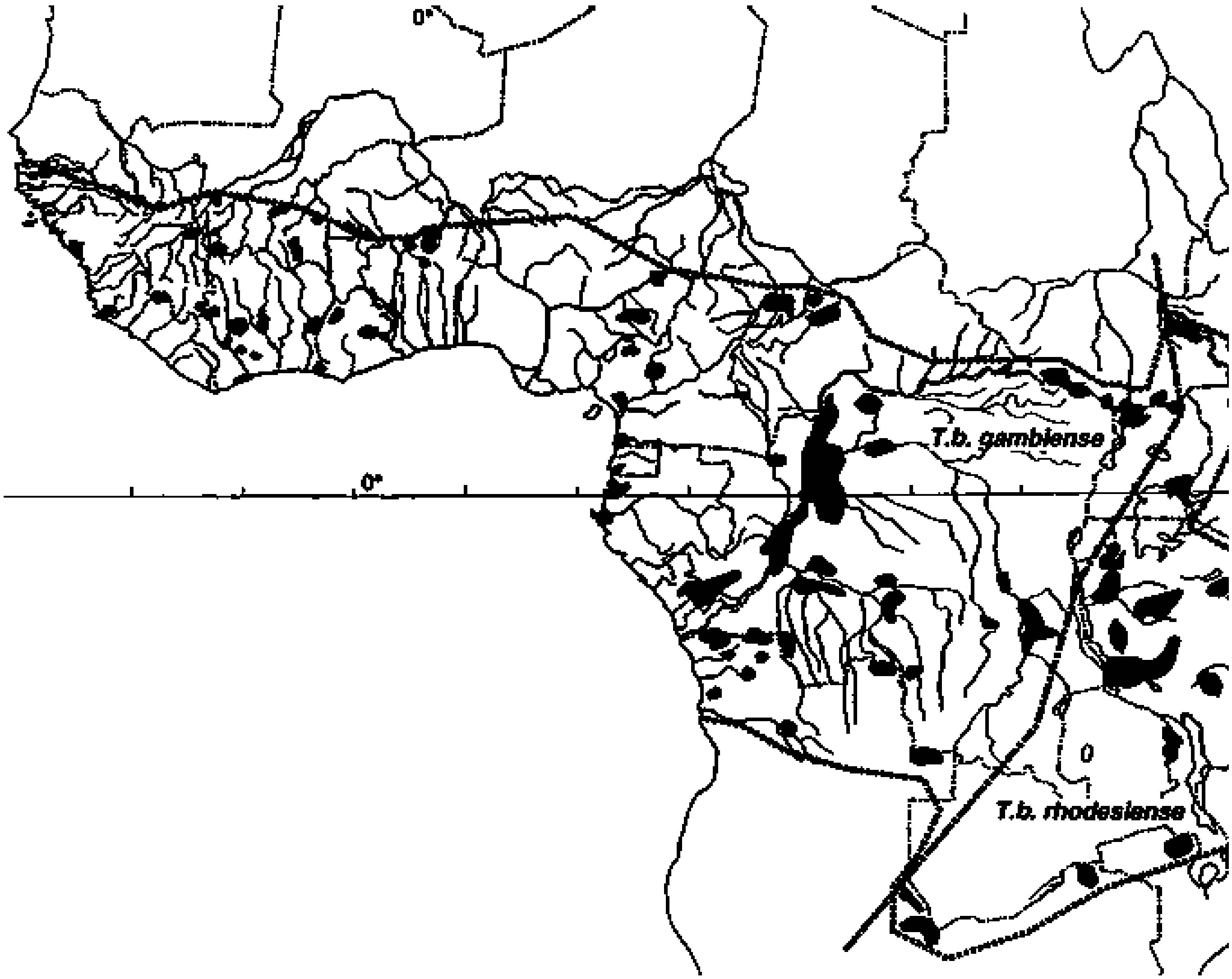

Fig. 2.3. Geographical distribution of foci of gambiense and rhodesiense sleeping sickness, 1996 (© WHO)
WHO 96140

Fig. 2.4. Transmission of gambiense sleeping sickness occurs most frequently along rivers and lakes.

Infection usually takes place where humans enter the natural habitat of the tsetse flies.

Gambiense sleeping sickness is mainly transmitted by tsetse flies belonging to the *G. palpalis* group. These flies attack people at places along rivers such as river crossings, lakeside villages, and bathing and washing places, and also near water holes, plantations and along roads bordered by vegetation (Figs. 2.4 and 2.5).

Rhodesiense sleeping sickness is transmitted by savanna species belonging to the *G. morsitans* group. These species normally feed on wild animals that inhabit savannas and woodlands, such as the bushbuck, or on domestic animals, such as cattle and goats. They also attack people who live in or enter these areas, for instance farmers, herdsmen, fishermen, hunters, travellers and collectors of honey. In some epidemic areas (e.g. near Lake Victoria) rhodesiense sleeping sickness is transmitted in the peridomestic environment from person to person or from domestic animals to humans by *G. f. fuscipes* of the *G. palpalis* group (Fig. 2.6).

Clinical symptoms

Among the first symptoms and signs of sleeping sickness are headache, irregular fevers, swollen tissues and joint pains (Fig. 2.7). At a later stage the parasites invade the brain, which usually leads to mental disorders, coma and death. There is often a latent period before any obvious symptoms or signs appear, which may last for months or years in gambiense sleeping sickness. This latent period does not exist or is short in rhodesiense sleeping sickness. Gambiense infections usually progress slowly while rhodesiense infections are acute. If untreated, both gambiense and rhodesiense infections are fatal.

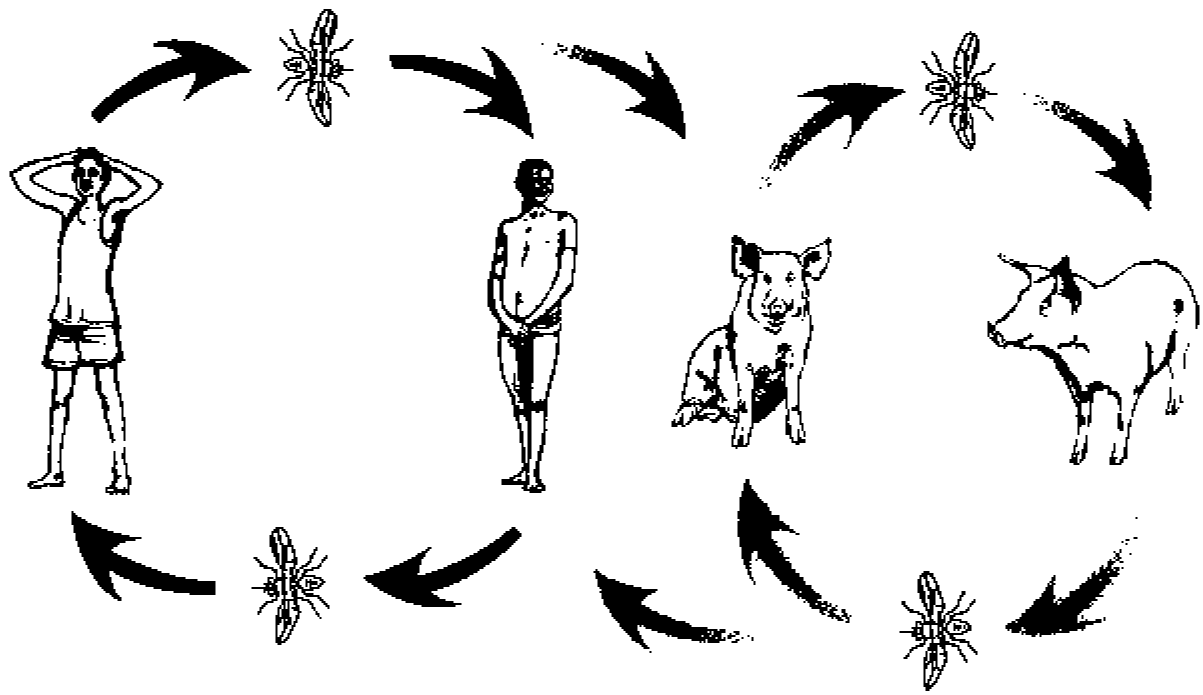

Fig. 2.5. Transmission cycle of gambiense sleeping sickness.

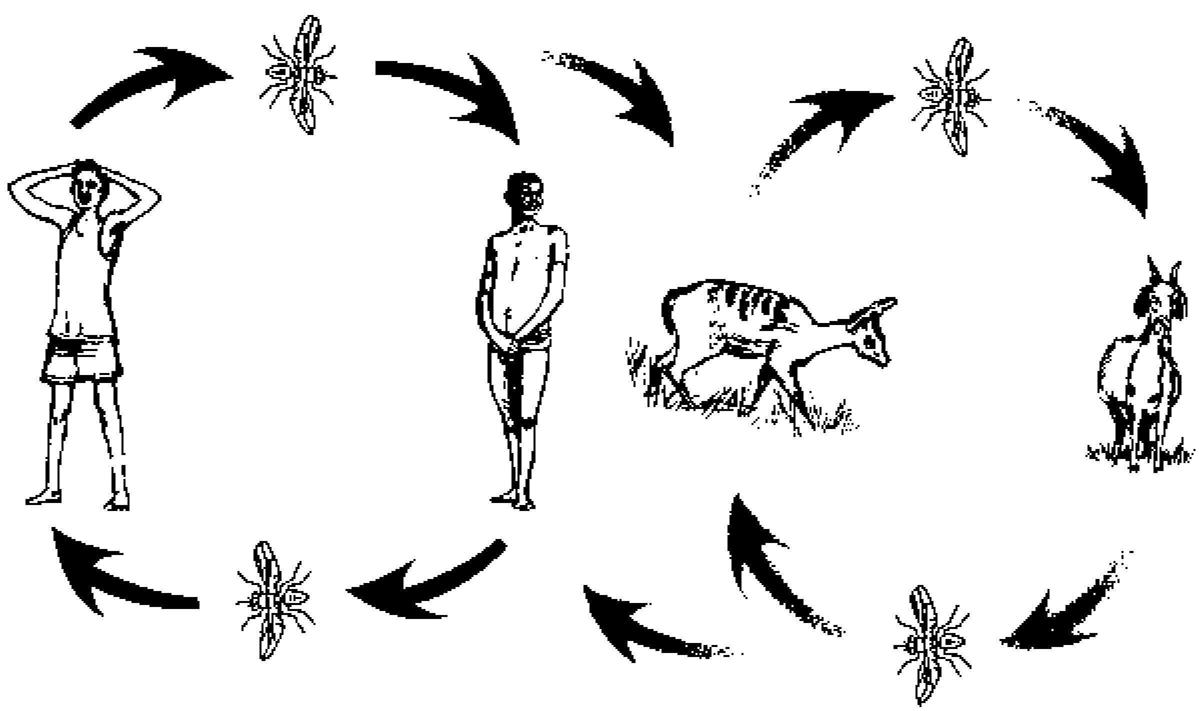

Fig. 2.6. Transmission cycle of rhodesiense sleeping sickness.

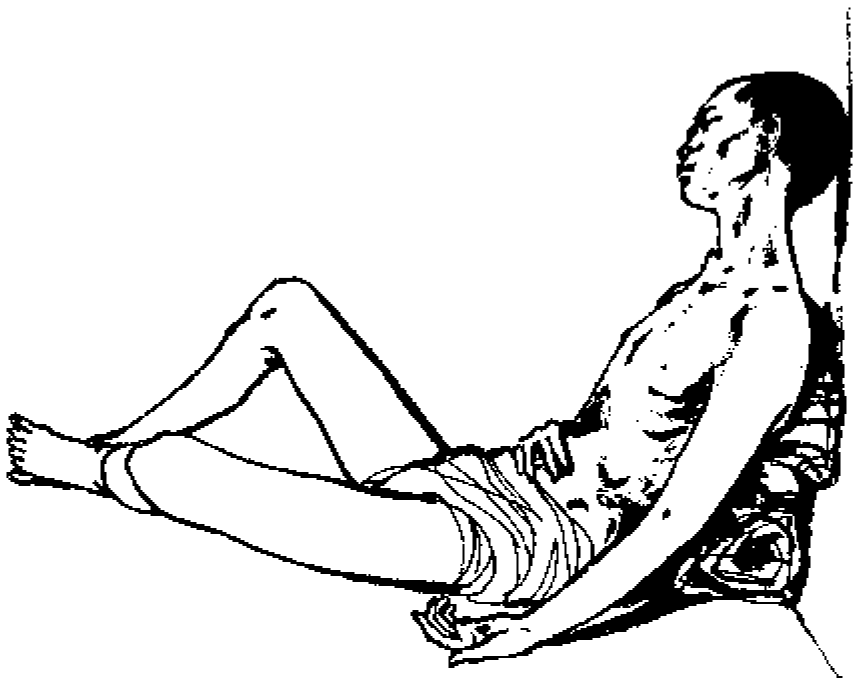

Fig. 2.7. African sleeping sickness usually starts with headaches, irregular fevers, swollen tissues and joint pains. At a later stage the brain becomes affected, which results in mental deterioration, coma (the sleeping stage) and death.

Treatment

Infection cannot be prevented through chemotherapy. In the past, pentamidine was used but it is no longer believed to be effective.

In the early stages of the disease, when the central nervous system is not yet involved, treatment is possible: suramin sodium is used for rhodesiense infections and is administered intravenously; pentamidine, used for gambiense infections, is usually administered intramuscularly, although slow intravenous infusions have been shown to be equally effective. Both drugs have side-effects.

In the late stage, when the central nervous system is involved, the chances of achieving a cure are diminished. Until recently, melarsoprol was the only available drug for treatment of the late stages of both gambiense and rhodesiense sleeping sickness. The drug carries a risk of serious side-effects, which may be fatal, and must be administered under strict medical supervision. It is not recommended for use in the early stages of the disease.

In 1994, a new drug, eflornithine, was used successfully for the treatment of all stages of gambiense sleeping sickness. However, the production of this drug ceased at the end of 1995.

Prevention and control

The current strategy for sleeping sickness control is based on active and passive case detection (surveillance), treatment of infected people, and, when appropriate, tsetse control. In recent years, community participation in national programmes has been sought to ensure the sustainability of control activities.

Surveillance aims to reduce the human reservoir of infection and to make treatment less hazardous through early detection. It also provides early warning of any increase in the prevalence of infections. As the symptoms are generally mild in gambiense sleeping sickness, surveillance involves screening programmes conducted by mobile teams. In areas with rhodesiense sleeping sickness, surveillance relies mainly on individual patients coming to rural health facilities.

Diagnosis is carried out by serological tests: the direct card agglutination test for trypanosomiasis (CATT) is used to identify patients with gambiense infections while the indirect immunofluorescent test (IFT) is used to detect rhodesiense infections. Seropositive cases are confirmed by the microscopic detection of parasites in blood or in lymphatic or spinal fluid.

Where recent epidemics have occurred, this was mostly due to a decline in surveillance activities and increased population movement. Control activities have also been hampered by a lack of suitable personnel and financial resources.

The main objective of vector control is to reduce contact between people and flies. The most promising and environmentally acceptable vector control methods currently available are those in which tsetse fly traps and insecticide-treated screens are used. Under epidemic conditions, when very quick action is needed, insecticides may be sprayed on to resting sites of tsetse flies in vegetation.

Control measures

A variety of methods can be used to control tsetse flies. Before suitable insecticides became available, control efforts mainly involved the removal of the woody vegetation forming the fly's habitat. In areas of rhodesiense sleeping sickness, the primary food sources of the flies, wild game animals, were killed or removed. The tsetse flies then eventually disappeared because of food shortage. These methods have largely been abandoned and today insecticide spraying is used along with traps and insecticide-impregnated targets.

Traps and insecticide-impregnated screens

Traps and screens are an effective means of tsetse control. They are cheap, easy to transport, and completely safe for the user and the environment. Once a suitable trap or screen has been developed for a given area, no special expertise is needed in order to use it. This method is therefore ideally suited for anyone seeking to provide cheap and effective community protection.

Mode of action and design

For many years research workers have used specially designed traps to collect tsetse flies for study purposes. The flies search for blood-meals or resting places partly or wholly by sight, and are attracted by large objects that move or contrast with the landscape. Certain colours, especially blue, attract many tsetse flies (*2*). The blue screens of the trap are contrasted with black screens to make the flies settle. The flies subsequently move towards the upper part of the trap in the direction of the light. There they may become trapped in a specially designed bag.

An effective trap attracts all the flies from a distance of approximately 50 m, i.e. their range of vision. Migrating flies that pass nearby are also attracted. Thus a trap can remove flies from an area much larger than the zone of immediate attraction. Flies that enter the trap may die because of exposure to an insecticide impregnated in the trap material or because they are exposed to the sun. Impregnated traps have the extra advantage that flies settling on the outside, but not entering, are also killed.

The basic design of traps and screens is applicable in all areas of Africa with tsetse flies but some modifications may be needed to make them more effective under local conditions. Attractive odours are available for the control of certain species that transmit animal trypanosomiasis (*Glossina morsitans* group).

The impregnated screen, a simplification of the impregnated trap, consists of a large piece of cloth of a colour attractive to tsetse flies. The impregnated insecticide kills the flies when they land on the screen. Impregnated screens are effective only as long as the insecticide lasts.

Use of traps by individuals or communities

Since tsetse flies fly considerable distances, traps should be used on as large a scale as possible. This requires the participation of several members of a community and preferably of several communities or even districts. However, isolated communities in forested areas, for example in the Congo, have successfully implemented their own protection measures. Individual farmers can protect themselves in a forest environment by placing traps or screens on their plantations or camp sites.

Models of traps and screens

The biconical trap

The biconical trap was one of the earliest models to be designed (Fig. 2.8) (*3*). Unlike the two later models it is not used in large-scale control operations because of its relatively high price and complicated structure. However, it is still used to monitor the effectiveness of tsetse fly control activities.

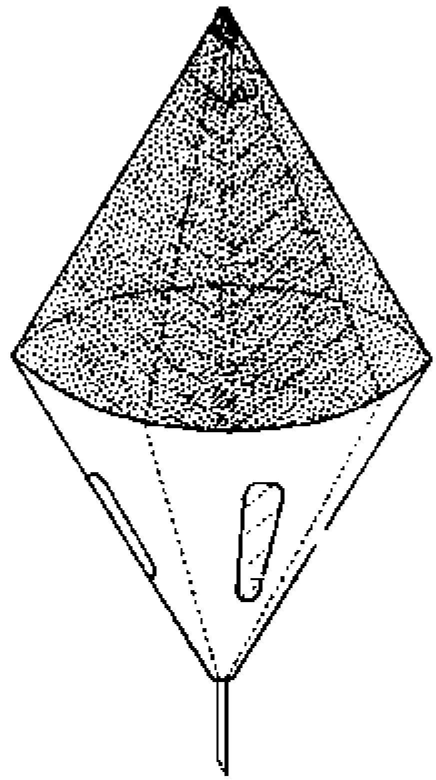

Fig. 2.8. The biconical trap. The cones are separated into four compartments by four segments of black cloth (© WHO).
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The lower cone is made of electric-blue cotton or synthetic cloth. The inner part is divided into four compartments by four segments of black cloth. Four openings allow the flies to enter the blue cone. The upper cone is made of mosquito netting, and flies are caught in the top part, by a simple trapping device.

The Vavoua trap

This trap was designed in Vavoua, Côte d'Ivoire (Fig. 2.9) (*4*). It consists of a cone of mosquito netting attached to a circular piece of galvanized metal wire and placed above three screens joined together at angles of 120°. Each screen is two-thirds blue and one-third black, the black parts being joined together in the middle. The flies land on the black parts, fly upwards towards the light and are caught in the upper cone. This trap can either be used with a catching device or be impregnated with an insecticide.

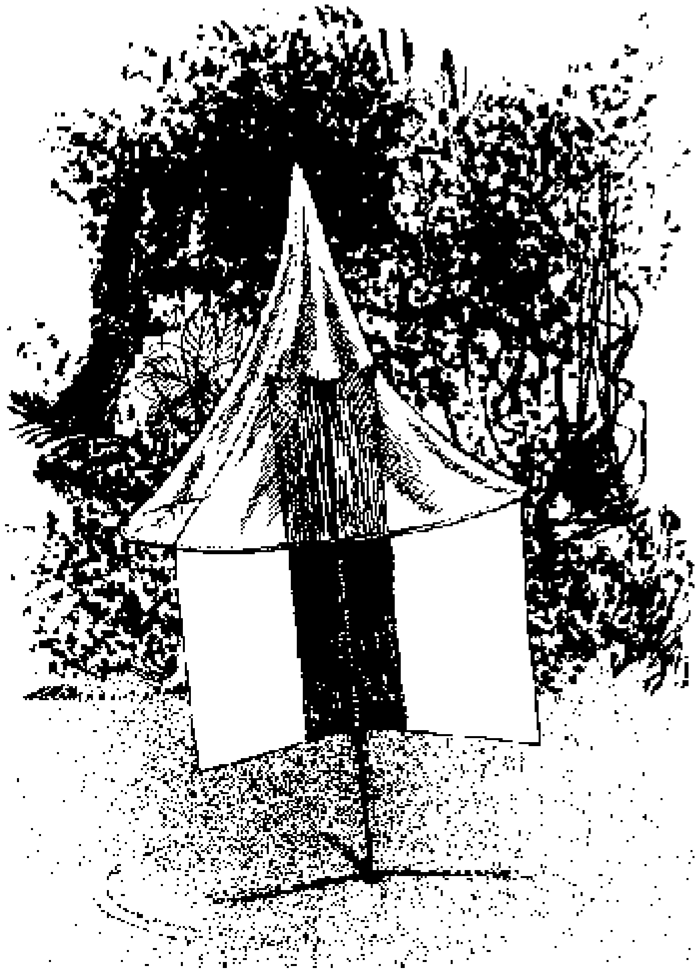


Fig. 2.9. The Vavoua trap.

The pyramidal trap

The pyramidal trap consists of a pyramid of transparent white mosquito netting surmounting two black and two blue screens arranged in the form of a cross (Fig. 2.10). It was developed in the Congo (*5*) and is currently being extensively used in Uganda. If provided with a catching device at the top this trap can be used without an insecticide and is then suitable for areas with high rainfall.

In large-scale programmes it offers the advantage that it is very compact for storage. It can be given its final shape in the field by extending the screens with two sticks.

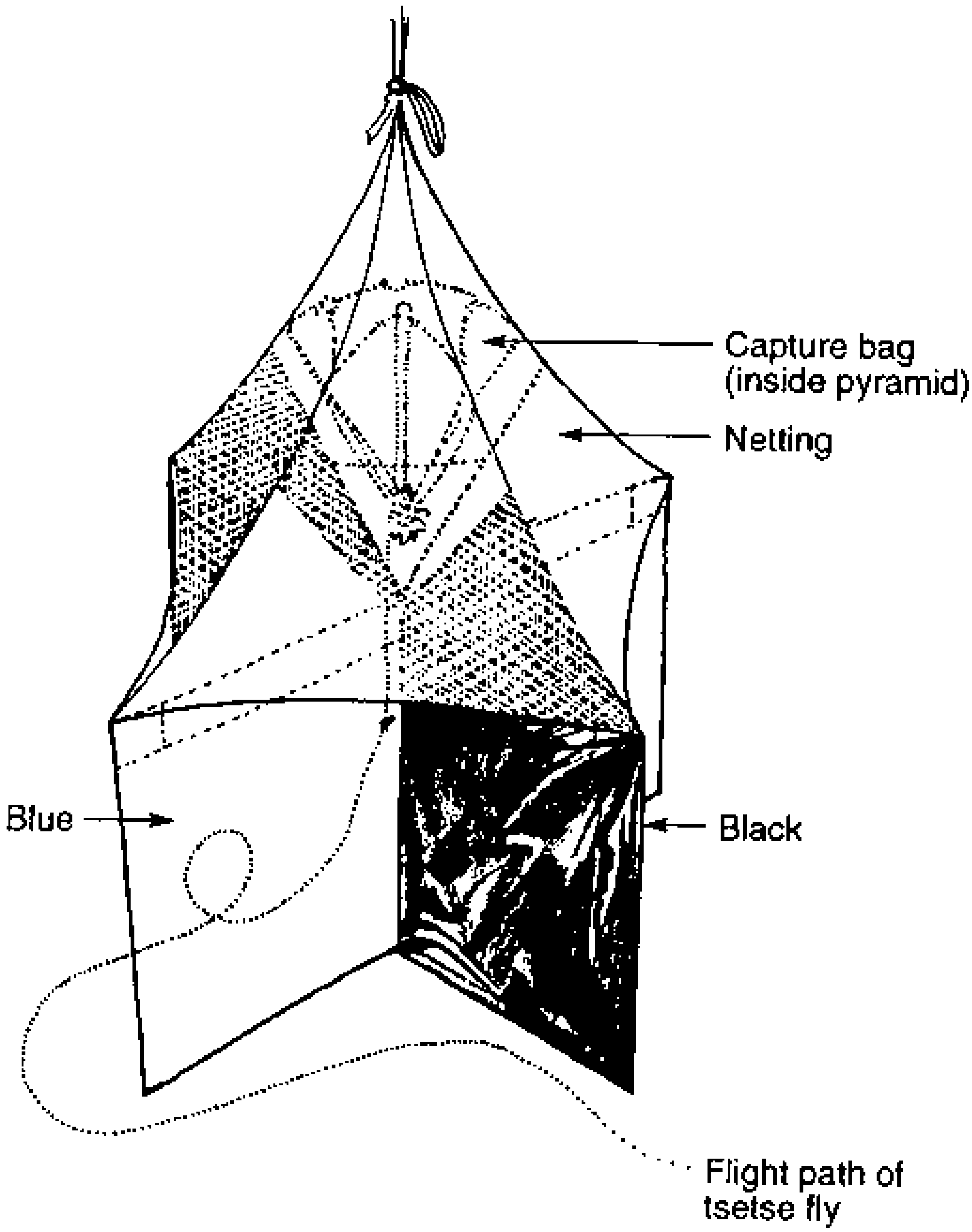


Fig. 2.10. The pyramidal trap.

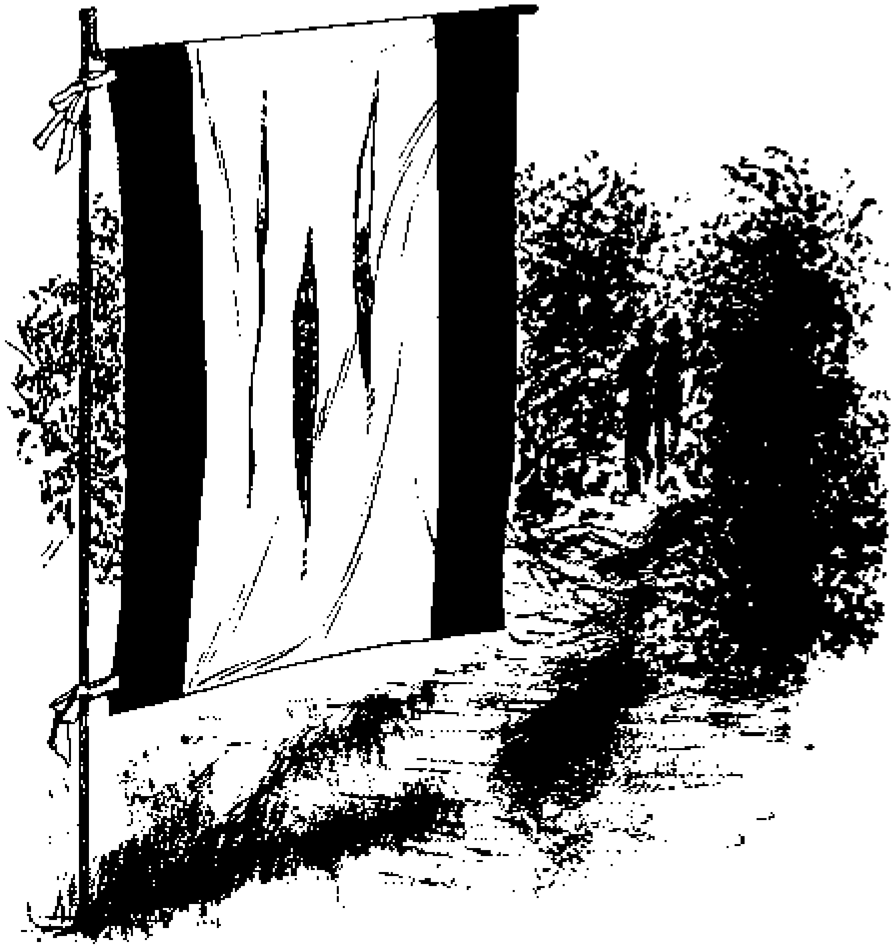


Fig. 2.11. An impregnated screen suspended from a metal support. Slits can be made in the cloth to discourage theft and reduce the effect of wind.

Impregnated screens

Unlike traps, screens are effective in killing tsetse flies only when impregnated with an insecticide.

The most commonly used screen consists of a strip of electric-blue material made of cotton and polyester or plastic with a strip of black nylon sheeting on either side, giving a total size of about 1 m^2. The screen is attached to two wooden laths and suspended from a branch by means of a rope or from a metal support driven into the earth (Fig. 2.11) (*6*).

The flies are attracted to the blue material and then try to settle on the black area. It is therefore sufficient to impregnate the black strips only. Consequently, the black strips have to be made of a material that offers a good substrate for an insecticide; nylon seems to serve this purpose best.

Advantages and disadvantages of traps and screens

Screens

Screens are less complicated than traps, and cost roughly 70% of the price (7). Thus, with a given budget, a larger area could be covered with screens or a higher density of devices could be used over the same area. However, the necessity to re-impregnate the screens more often is a major disadvantage.

Traps

Traps attract more flies than screens because they are visible from all sides. They require less handling, since they remain effective even after the insecticide has lost its activity.

Traps with or without insecticide impregnation

Impregnated traps are 10-20% more effective in killing tsetse flies than unimpregnated traps. With unimpregnated traps it would take more time to reach the same level of control. Unimpregnated traps have to be used with a permanent catching device, such as a catching bag. For quick action these traps can also be impregnated. When the insecticide has lost its activity, after 3-6 months, the traps continue to be effective in catching flies.

Placement

The method of placement depends on local conditions and preferences. Traps can simply be put on a wooden or metal pole. In open windy areas the suspension of a trap from a branch (Fig. 2.12) or other support probably gives more wind-resistance than putting it on a pole. Hanging traps in vegetation entails the risk that they will become entangled. The use of purpose-built supports has the important advantage that the most suitable, sunny sites can be selected (Fig. 2.13).

Screens can be attached to two wooden laths or suspended from the branches of trees by ropes. However, screens are even more easily entangled in vegetation than traps and it is recommended that they be suspended from metal or wooden supports (see Fig. 2.11).

The best location for traps and screens depends on the type of habitat. In general the best places have high densities of tsetse flies and are open and sunny. Such sites offer good visibility; flies that settle on the black screens are more likely to fly upward into the brightly lit upper cone of gauze where they are retained.

Fig. 2.12. Traps can be suspended from suitable branches to hang 30-50 cm above the ground.

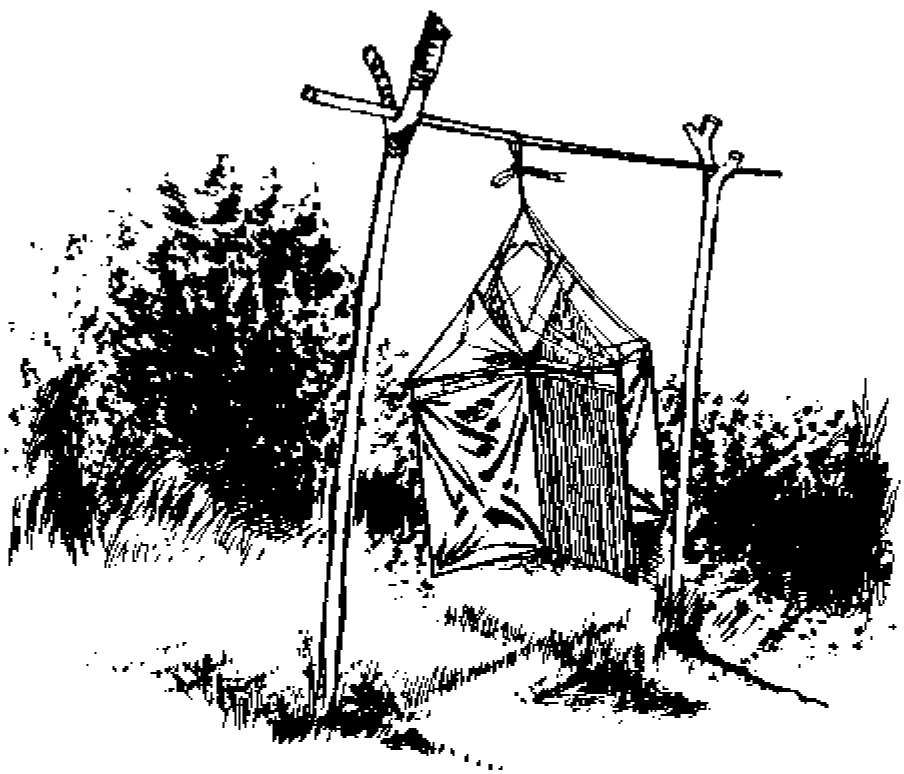


Fig. 2.13. Traps can be suspended from a purpose-built support in a sunny site.

Once the area has been selected, the trap can be moved to obtain maximum efficiency. To find out whether an impregnated trap is in a good place, count the total number of flies collected each day during the first week of operation. The results can be compared with those obtained with other traps, and unproductive traps can be moved to new sites.

Gallery forests along rivers

Tsetse flies often search for a blood-meal by following river banks. This habitat is very suitable for the use of traps and screens, which can easily be put in the flight paths of the flies. Bathing and washing places should be protected by a trap or screen placed at the beginning of the trail leading away from the river (Fig. 2.14). If possible others should be placed around the area. Studies have shown that maximum efficiency can be obtained by placing traps or screens at intervals of 300 m over a distance of about 5km, both upstream and downstream of the area to be protected.

Fig. 2.14. Traps should be placed near bathing and washing places.

Traps or screens should be placed:

- as close as possible to the banks of the river for the best possible visibility;

- in the most open and sunny places;

- in greater number where people frequently visit the river.

The best time to install traps or screens is at the end of the rainy season after the flood waters have gone down because:

- insecticides are likely to be washed out of the material during the rainy season;

- the tsetse fly population concentrates in the gallery forest during the dry season;

- the population of flies is older (there being a higher pupal mortality during the rainy season), and older flies are more responsive to traps.

Fig. 2.15. To protect a village, traps should be placed at the forest edge, at places where tsetse flies commonly attack.

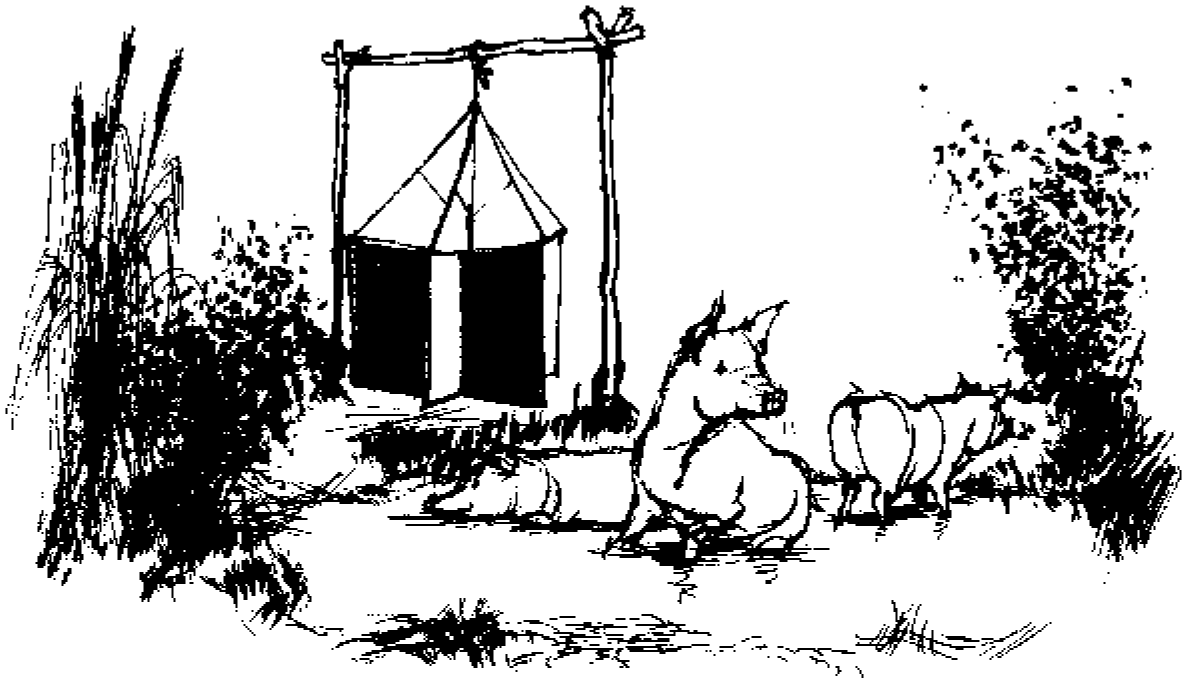


Fig. 2.16. Flies are attracted to domestic animals and can be caught by a trap near the site where the animals are kept.

Villages surrounded by forest

Tsetse flies rest in the vegetation surrounding villages and attack people and domestic animals near the forest edge at swampy areas, sources of water, water standposts, toilets, bathing places and so on. Around villages, traps should be used rather than screens, and should be placed where the tsetse flies are likely to attack (Figs. 2.15 and 2.16). Traps with a collection bag will allow the villagers to evaluate the effectiveness of control efforts.

Routes and paths along a forest edge

Tsetse flies often attack people on paths along a forest edge. Screens can be used because they can be easily re-impregnated when placed along a path. They should be placed at right angles to the path to be easily visible to flies flying along the path (Fig. 2.17).

Plantations

Tsetse flies also attack people working in their gardens and on coffee or cacao plantations. They can be protected by traps or screens placed along the boundaries of plantations and forests (Fig. 2.18). Screens are preferable to traps in plantations because the necessary large numbers are more affordable and there is no problem of access for re-impregnation.

Water collection points in forested areas

Water is collected not only from rivers and streams but also from isolated wells, pools, pits and ponds. When such places are in a forest environment they provide a favourable habitat for the tsetse fly. One or two screens or traps should be installed near these points (Fig. 2.19).

Fig. 2.17. Screens should be placed along forest paths at intervals of 200 m.

Fig. 2.18. People working in gardens and on plantations can be protected by traps or screens placed near forest edges and along trails inside plantations.

Fig. 2.19. Tsetse flies often attack people near water collection points surrounded by dense vegetation.

Maintenance

It is important to clear the area surrounding traps and screens of emerging vegetation to allow clear visibility for the flies (Fig. 2.20). Where vegetation grows rapidly, frequent clearing is needed. Lost traps or screens have to be replaced; those that become torn or damaged have to be repaired.

Re-impregnation

After the initial impregnation, screens have to be re-impregnated every 3-4 months or so. Since traps continue to function after the insecticide has lost its effect, re-impregnation may not be necessary. Traps often last 6-10 months. Screens may last up to two years, and are impregnated several times before being replaced. Old traps should be replaced by new and freshly impregnated traps after a period of, for example, eight months. In areas where the tsetse fly problem is limited to one season the traps or screens should be installed or re-impregnated at the beginning of the season.

Assembly

Materials needed (8)

Blue cloth

Blue cloth made of 33% cotton and 67% polyester, of about 200g/m^2, is recommended. This material is very resistant to wear. All blue colours will work to some extent but best results are obtained with electric or royal blue. A cheaper but probably less effective alternative is plastic sheeting of the same colour.

Fig. 2.20. Vegetation has to be cleared from the site of the trap in order to maintain good visibility for tsetse flies.

Black cloth

The best type of black cloth for application of insecticide is 100% nylon sheeting of about 44g/m^2.

Mosquito netting

The netting used in traps has to be of good quality, because it supports the whole structure. Synthetic materials are generally stronger and cheaper than cotton and are also preferable for impregnation. The best material is 100% nylon netting of about

$30 g/m^2$, which lasts longer than 100% polyester netting when exposed to the sun. A suitable durable alternative which can easily be obtained at local markets is the fabric used for making pockets in trousers.

Capture bag

Capture bags are made of mosquito netting.

The pyramidal trap (Fig. 2.21)[1]

- Cut two blue and two black pieces of sheeting with the dimensions shown in Fig. 2.21a.

- Cut four strips of cloth measuring 60 x 5 cm (b).

- Sew the four strips to the four pieces of sheeting as indicated. Fold back the extra 6 cm and stitch to form a pocket with the opening facing the middle of the piece of sheeting (c).

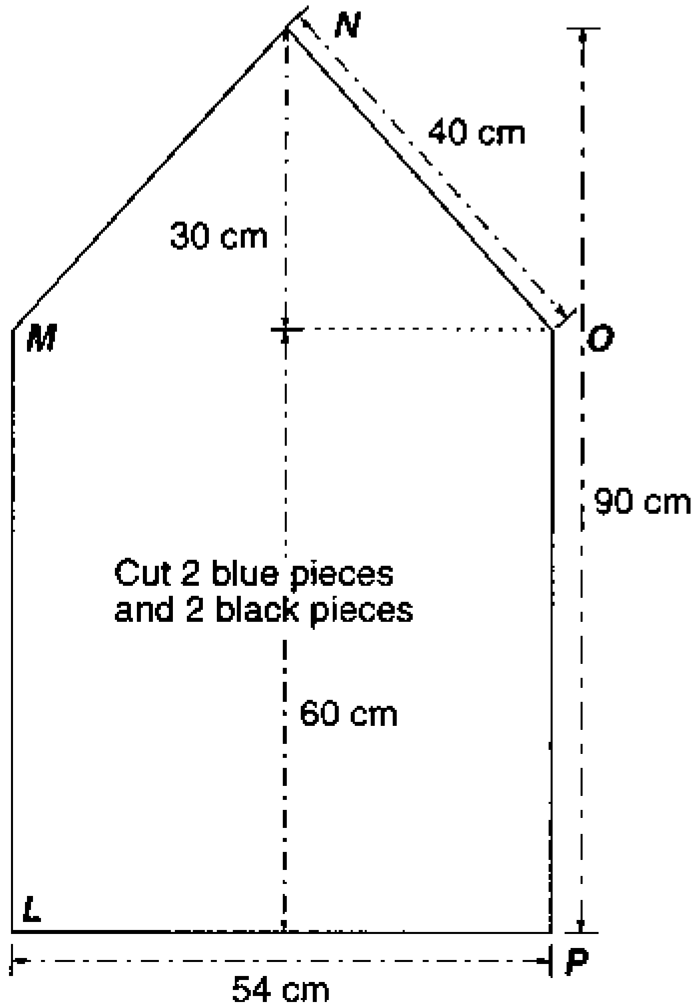
- Place the pieces on top of each other in alternate colours: black, blue, black, blue. Stitch the pieces together 3 cm from the edge opposite the pockets (d).

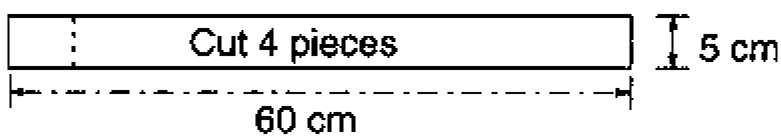
- Cut out the netting material in one piece with the dimensions shown in Fig. 2.21e, and mark the points A, B, C and D (shown as * in the drawing).

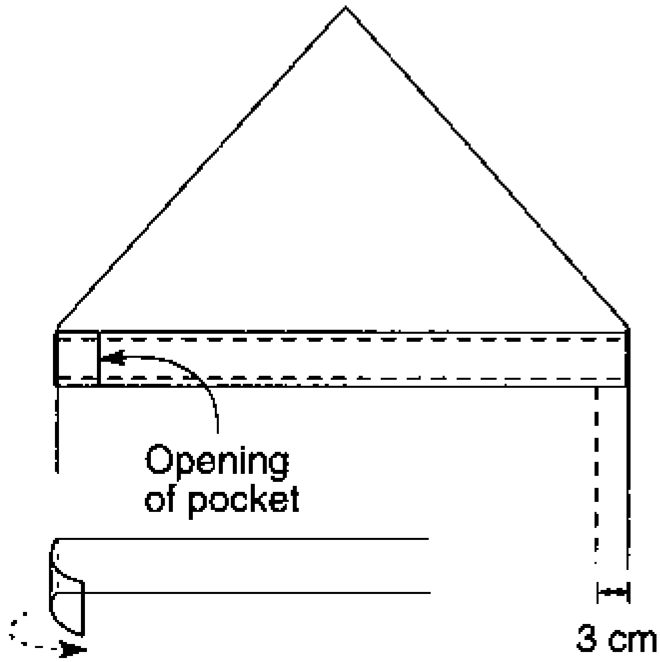
- Stitch a seam of 2 cm in the lower edge of the pyramid and close it by stitching side TV against side TU (f). Attach a 1-2 m strip of cloth or a string to the top of the pyramid. (The strip is for attaching the trap to a support in the field.)

[1] Based on a model used in Uganda in 1989 by J. Lancien.

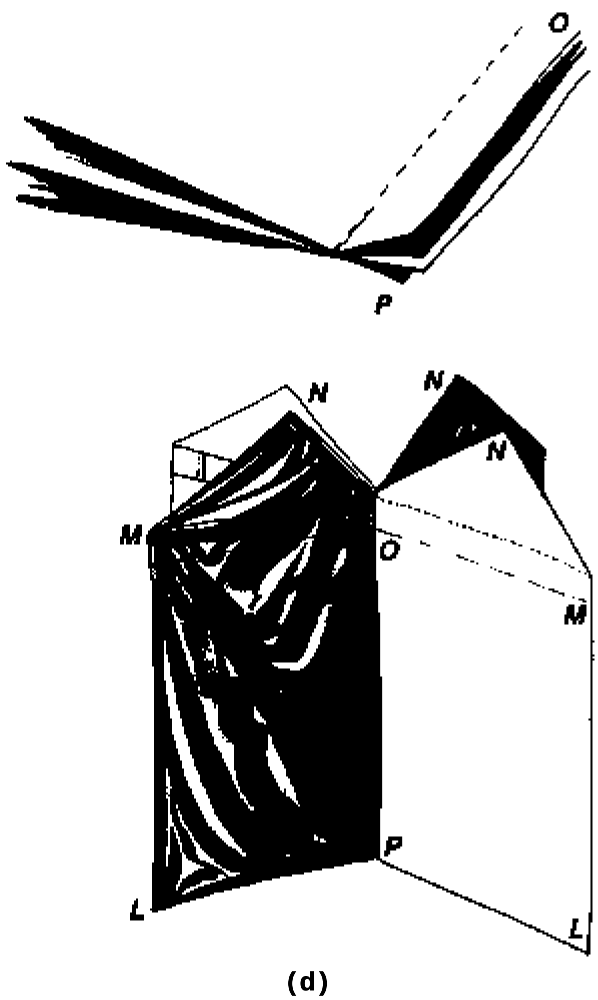
Fig. 2.21. Assembly of a pyramidal trap.


N
40 cm
30 cm
M
O
90 cm
Cut 2 blue pieces
and 2 black pieces
60 cm
L
P
54 cm
(a)

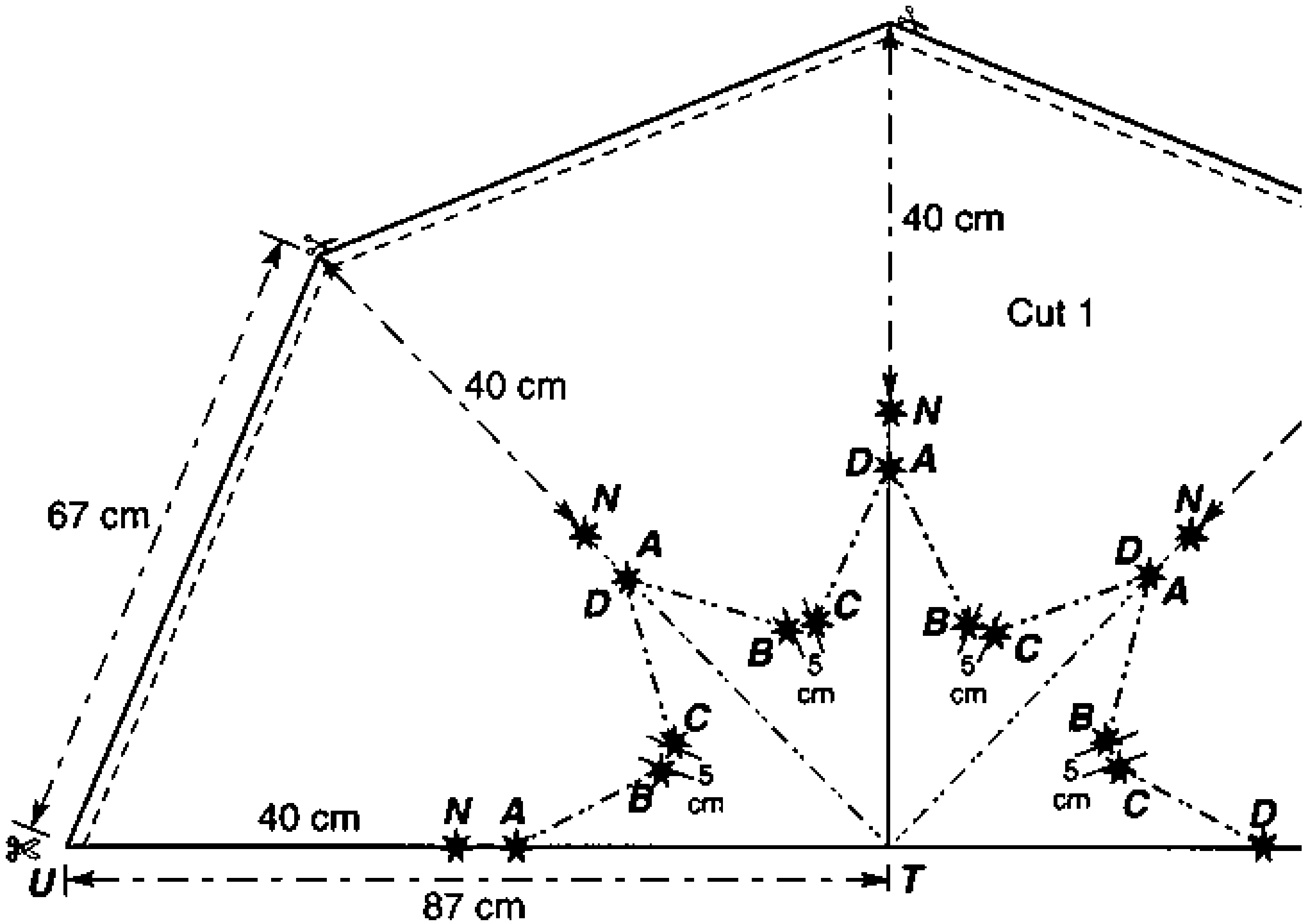

Cut 4 pieces
5 cm
60 cm
(b)



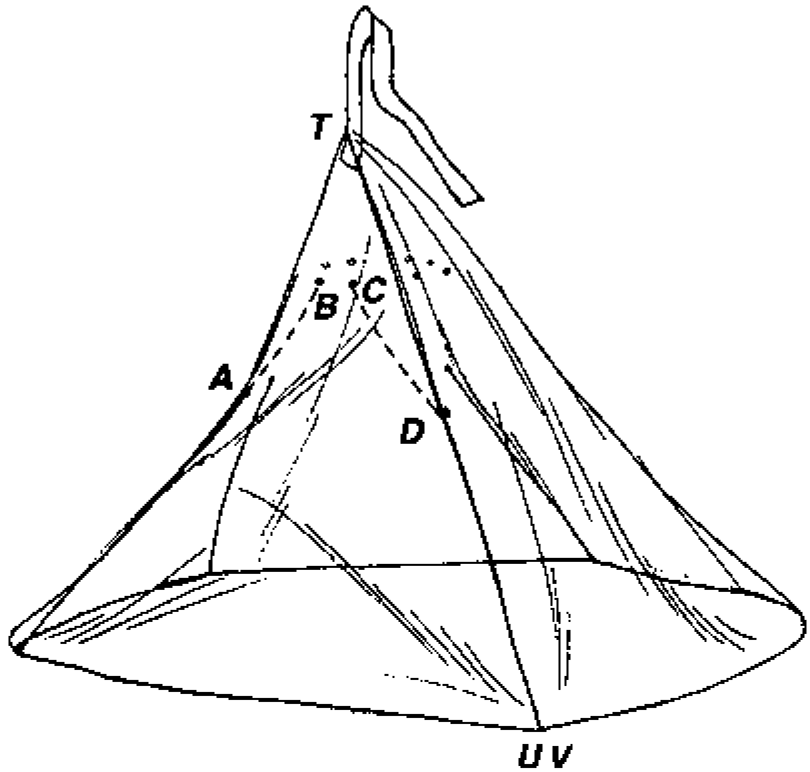
(c)



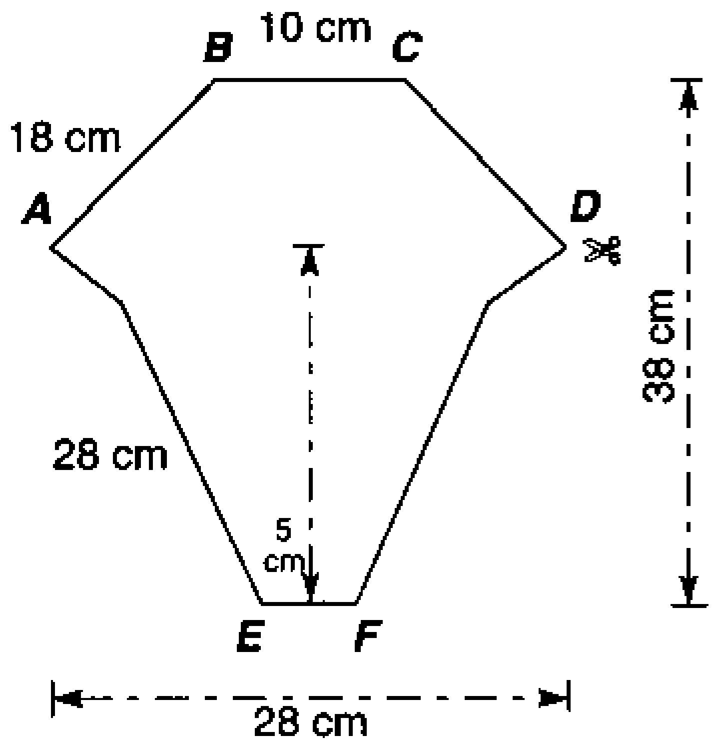
(d)


40 cm
Cut 1
40 cm
67 cm
N
D A
N
A
D
C
B
5
cm
B
C
5
cm
D
N
A
C
B
5
cm
B
5
cm
C
40 cm
N A
D
U
T
87 cm

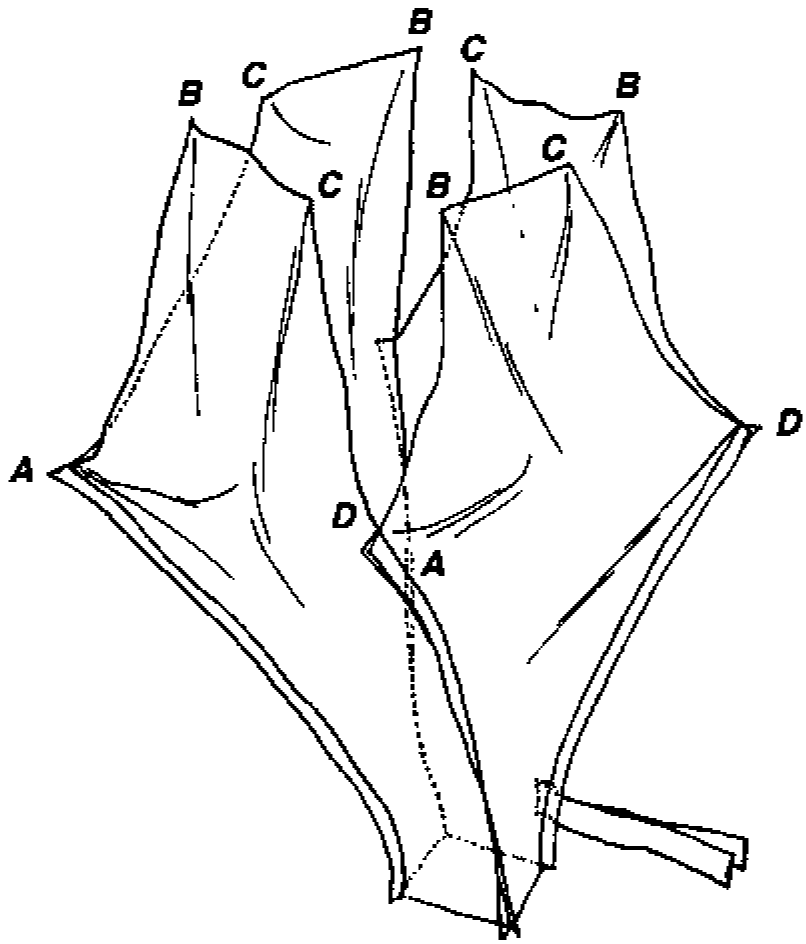
(e)



(f)

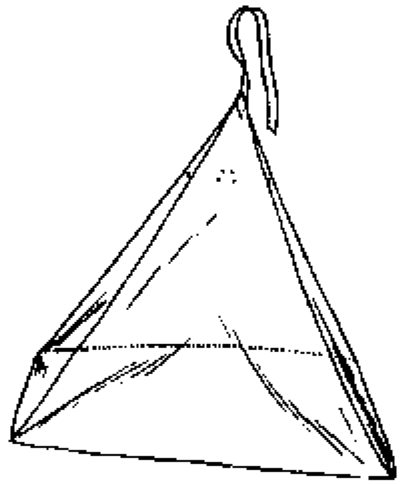


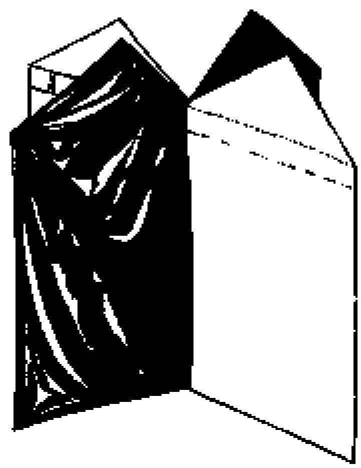
(g)



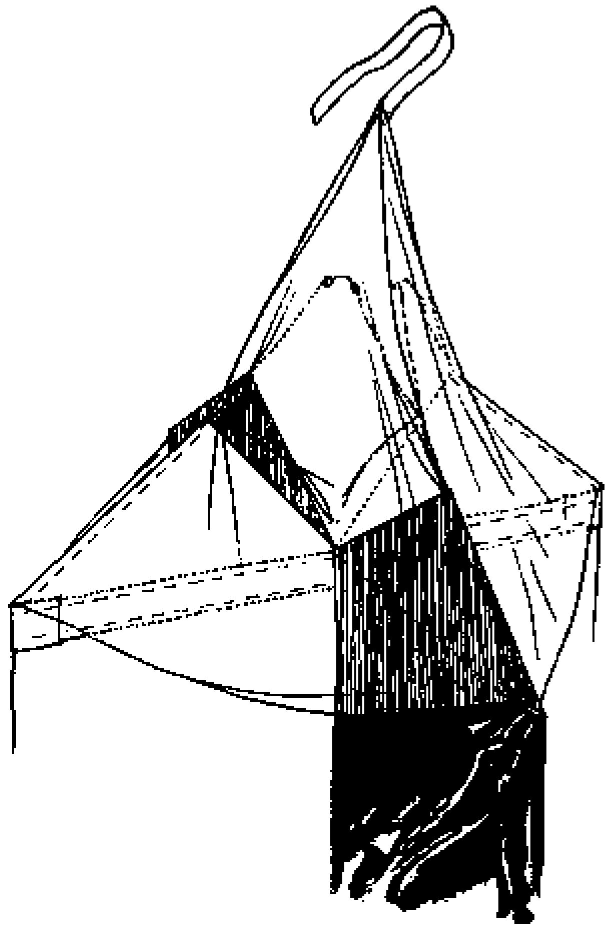
(h)

(i)

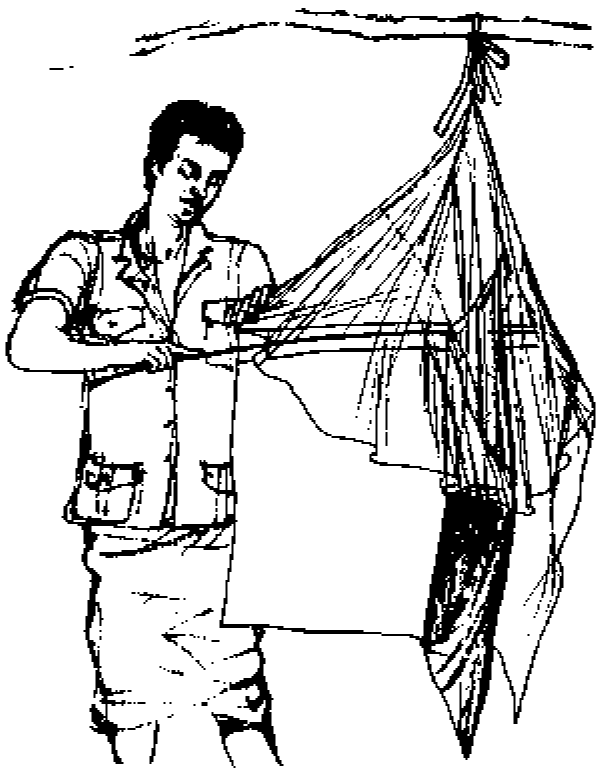




(j)



(k)



(l)

• Cut four pieces of mosquito netting material with the dimensions shown in
• Stitch the four pieces together along lines BE and DF. Attach a thin strip of cloth or a string near opening EF (h). This strip can later be used to close the bag.

• Attach the catching bag to the pyramid of mosquito netting. Stitch the bag with sides AB and CD to the corresponding lines (Fig. 2.21e) on the pyramid. Make sure that an opening is formed between A and C (Fig. 2.21i). (This allows tsetse flies to enter.)

• Attach the pyramid to the blue and black pieces (j). Fold the pyramid and place it over the four pieces of fabric as shown (k). Stitch the netting to sides OP of the pieces of fabric.

• The trap is given its final shape in the field after suspending it from a suitable support. The four sides are expanded by inserting two flexible sticks or laths measuring about 120 cm in length in the four pockets on the blue and black pieces (l). The two sticks cross each other at right angles and expand the two pieces of the same colour. In order to be able to insert a stick in the second pocket a hole has to be pierced in one of the pieces at right angles to it.

The Vavoua trap (Fig. 2.22)[1]

[1] Based on a model used in Côte d'Ivoire by Dr C. Laveissière.

• Cut out three pieces of black and three pieces of blue material with the dimensions shown in Fig. 2.22a and mark points A, B, C and D on the black pieces.

• Put one black piece on top of another and stitch along line AB.

• Fold the upper piece along line AB and put the third piece on top. Stitch along line CD.

• Stitch pieces 2 and 3 together along line CD on piece 2 and line AB on piece 3 (b).

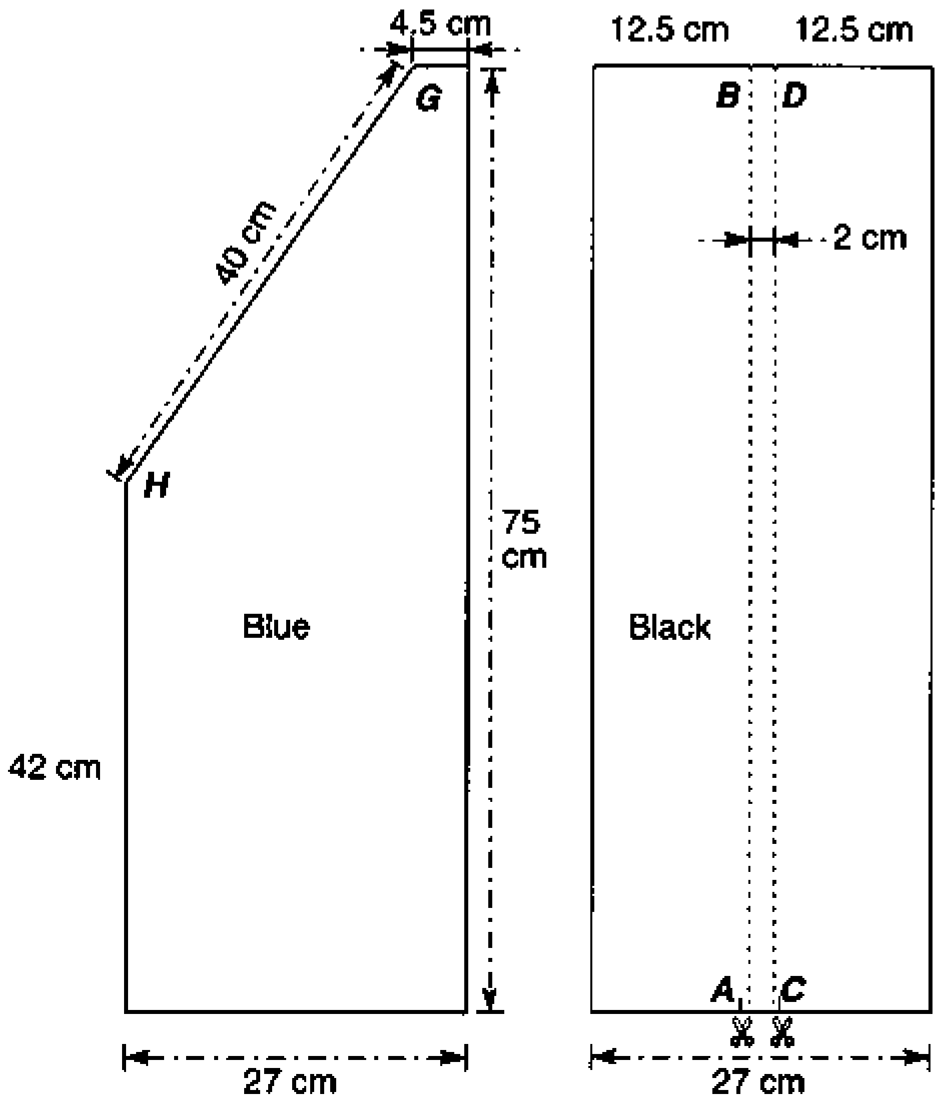
• Stitch the three blue pieces to the three black pieces as shown in Fig. 2.22c. Allow a seam of 1 cm. Make a seam on the lower edge of each of the three black-blue parts.

• Cut out three pieces of mosquito netting with the dimensions shown in Fig. 2.22d. Join the three pieces together in the shape of a cone and attach the cone to the black-blue material by stitching lines EF on the cone to lines GH on the blue material (e).

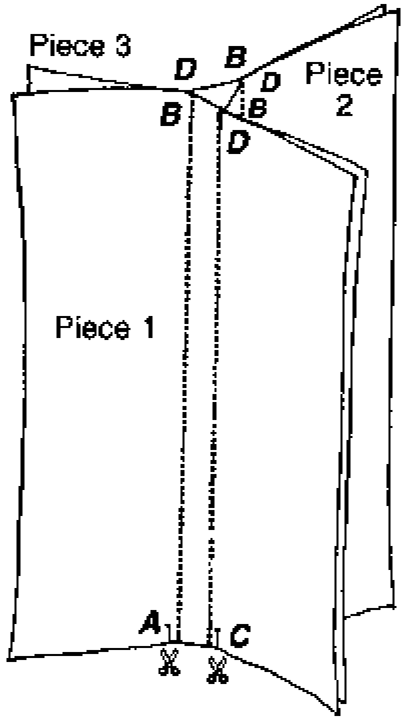
• Take a piece of metal wire measuring 250 cm in length, bend it to form a circle with a diameter of 80 cm, and twist or solder the ends together. Fold the edge of the netting cone over the wire hoop, pin in place and stitch a hem around the wire (e).

• The trap can be put up in the field by inserting a metal rod 150 cm long and 1 cm in diameter in the tube of material in the middle of the black screens. Place a ball of cotton in the top of the cone to prevent the metal rod piercing the cone (e).

Fig. 2.22. Assembly of a Vavoua trap.

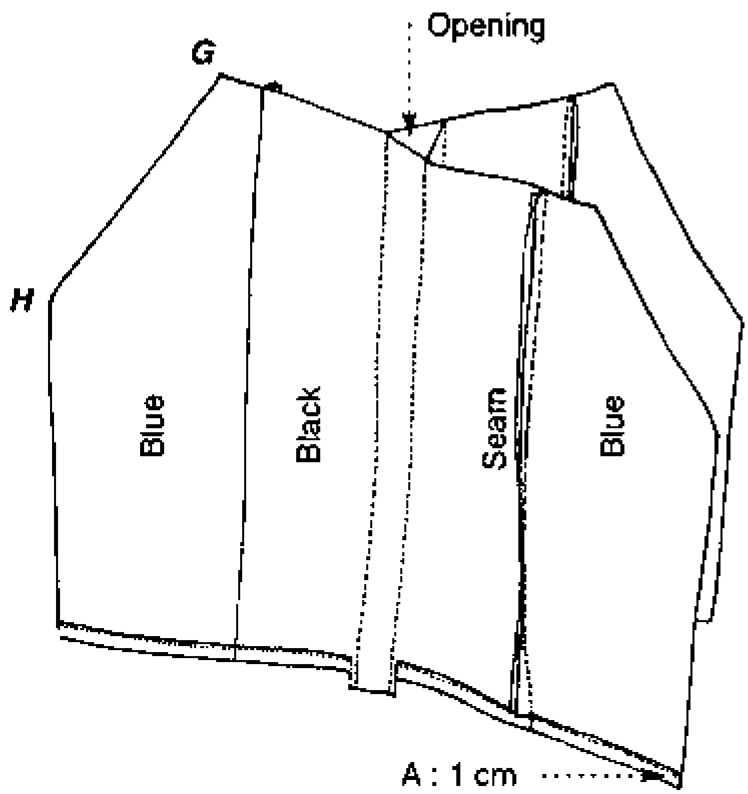

4.5 cm
40 cm
G
H
75 cm
Blue
42 cm
27 cm
12.5 cm
12.5 cm
B
D
2 cm
Black
A
C
27 cm

(a)



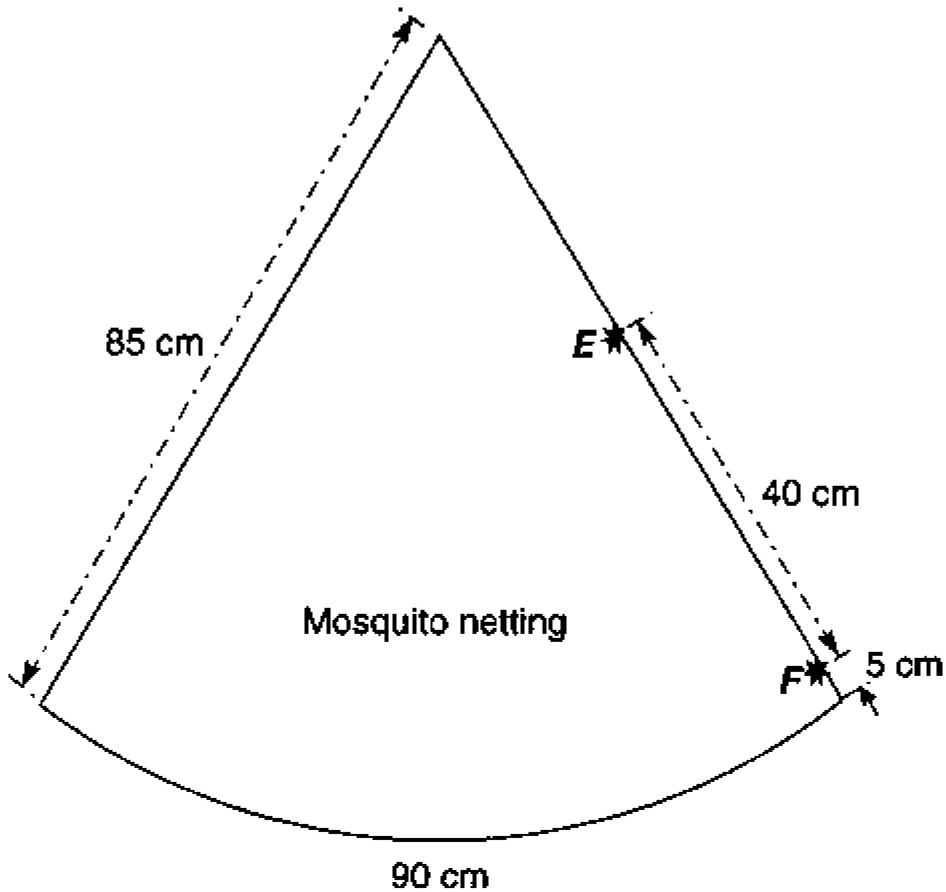
Piece 3
D
B
D
Piece 2
B
B
D
Piece 1
A
C

(b)

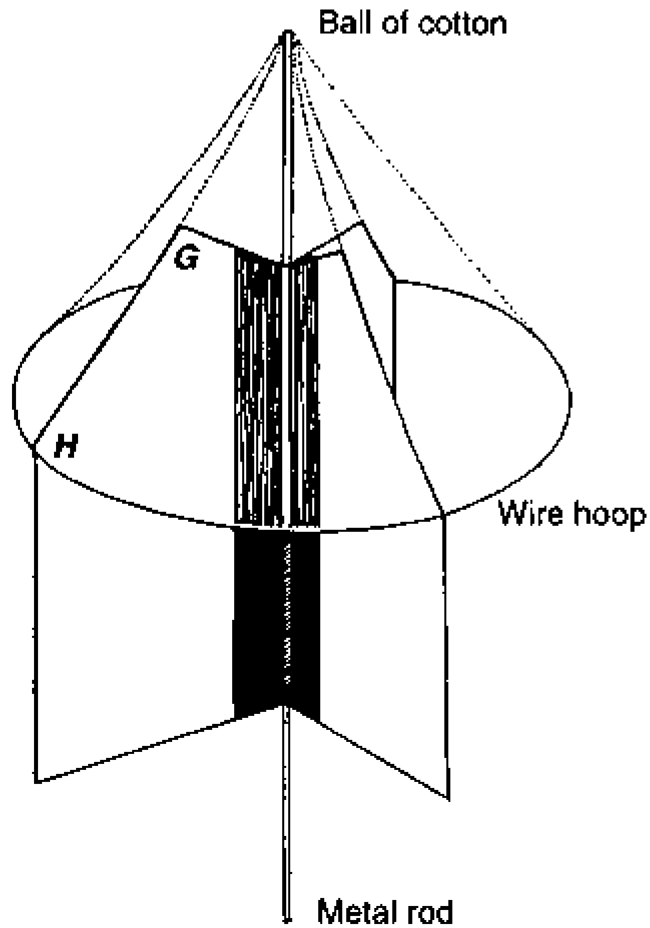


Opening
G
H
Blue
Black
Seam
Blue
A : 1 cm

(c)



(d)



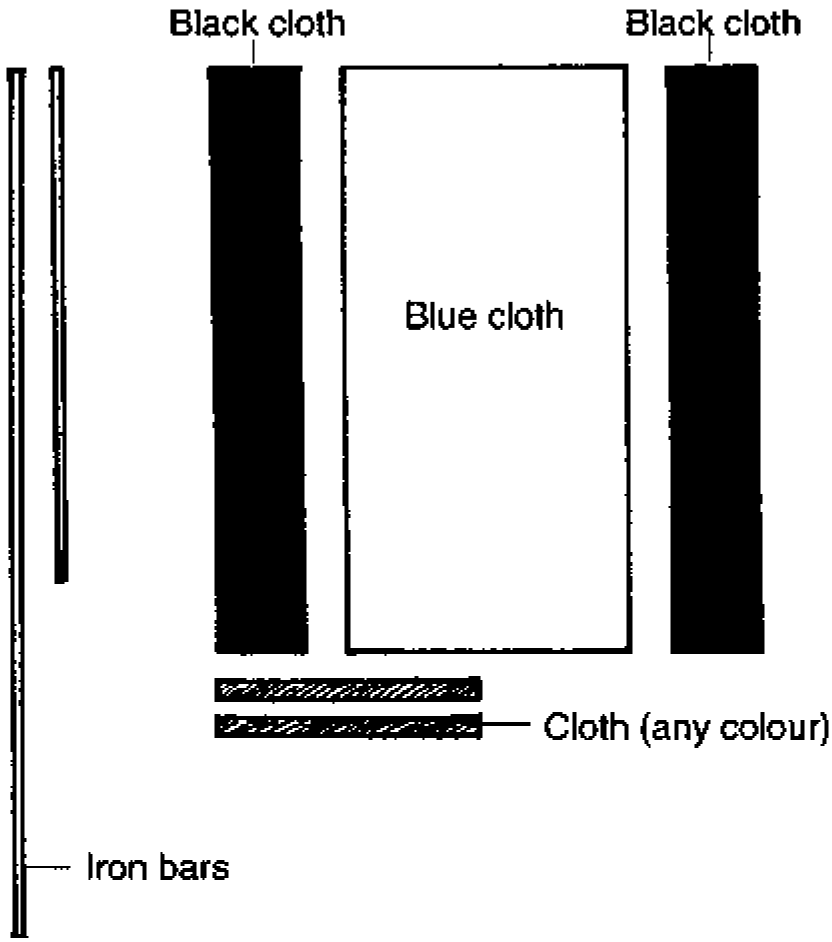
(e)

The screen (Fig. 2.23)[1]

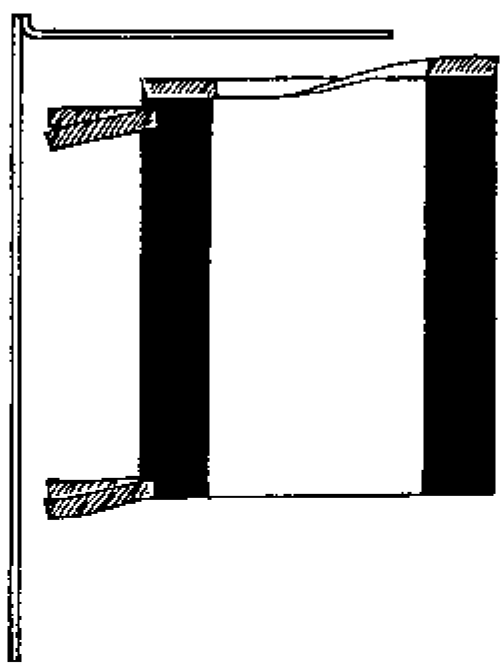
[1] Based on a model used in Côte d'Ivoire by Dr C. Laveissière.

- You will need (see Fig. 2.23a):
- an iron bar, 150 cm long and 1 cm in diameter;
- an iron bar, 85 cm long and preferably 0.8 cm in diameter;
- blue cloth, 110 x 50 cm;
- two strips of black cloth, 110 x 17.5 cm;
- two strips of cloth, 25 x 2 cm.

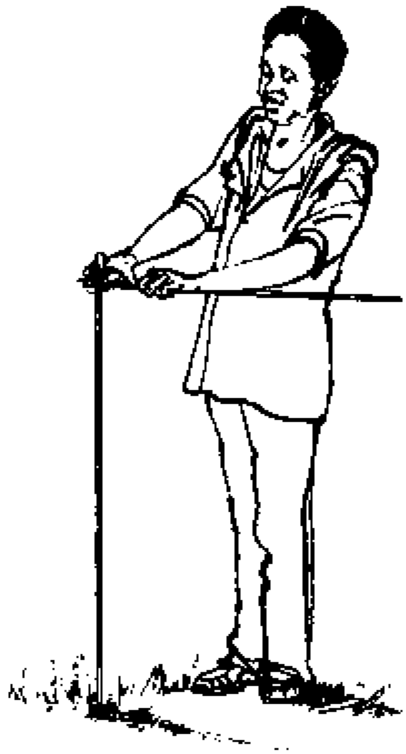
Fig. 2.23. Assembly of a screen.


Black cloth
Black cloth
Blue cloth
Cloth (any colour)
Iron bars

(a)

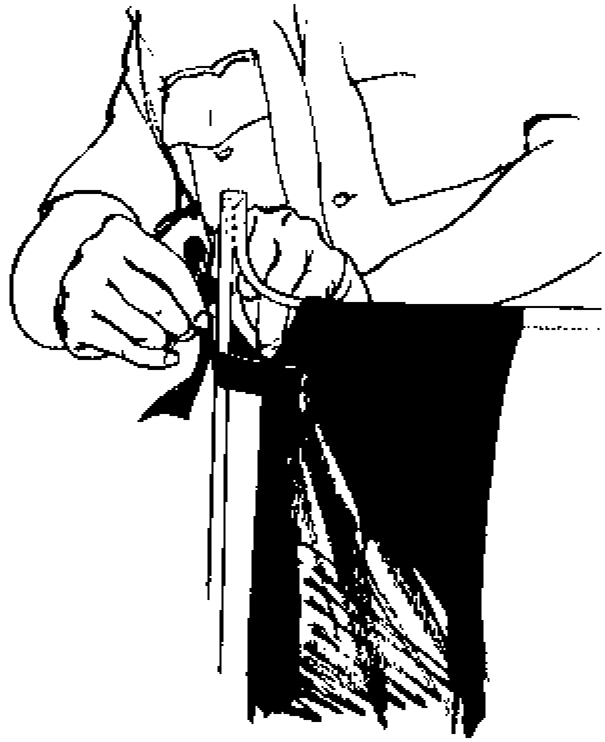


(b)



(c)

(d)



(e)

- Weld the two bars together at the final 2 cm as shown in Fig. 2.23b. Bend the shorter bar out at right angles to the longer bar. Sharpen the other end of the longer bar to make it easier to stick into the earth.

- Sew the strips of black cloth to either side of the blue cloth (b). With the seams the total width is 83 cm.

- Make a hem of 3 cm along the top of the cloth (b).

- Fold the tapes in half and sew them to the top and bottom of the long side of the screen (b).

- Install the screen in the field by hammering the long bar firmly into the ground (c), slipping the screen on to the short bar (d), and securing the screen by tying the tapes to the vertical bar (e).

Impregnation

Insecticides

The best insecticides for impregnation of traps and screens are the pyrethroids, especially deltamethrin, alphacypermethrin, lambdacyhalothrin, cyfluthrin and betacyfluthrin. They combine a long residual effect with quick killing of tsetse flies after only brief contact. Other insecticides e.g., DDT, are too slow in killing the insect, and much higher dosages would be needed.

The insecticides degrade as a result of exposure to sun, rain and wind. In general the residual effect of the insecticide increases with higher initial dosage. The persistence is influenced by the type of cloth used. With 200 mg of deltamethrin per m^2 or 380 mg of alphacypermethrin per m^2, effective activity is obtained for three months on cotton/polyester mix material and for up to six months on nylon. The pyrethroids are available in several formulations but soluble concentrates and emulsifiable concentrates provide the best results.

Procedure

In order to impregnate a trap or screen with a certain dosage of insecticide, the following information is needed:

- the approximate surface area in m^2 of the trap or screen (*a*);

- the amount of water required to saturate the trap or screen (*b*);

- the target concentration of insecticide (in grams per m^2) in the trap or screen material (*c*);

- the quantity of active ingredient per litre of insecticide concentrate (g/litre) (*d*).

The volume of emulsifiable concentrate in litres needed for the impregnation of one trap or screen is equal to:

$$(a \times c)/d$$

Fig. 2.24. The insecticide emulsion is measured with a measuring cylinder.

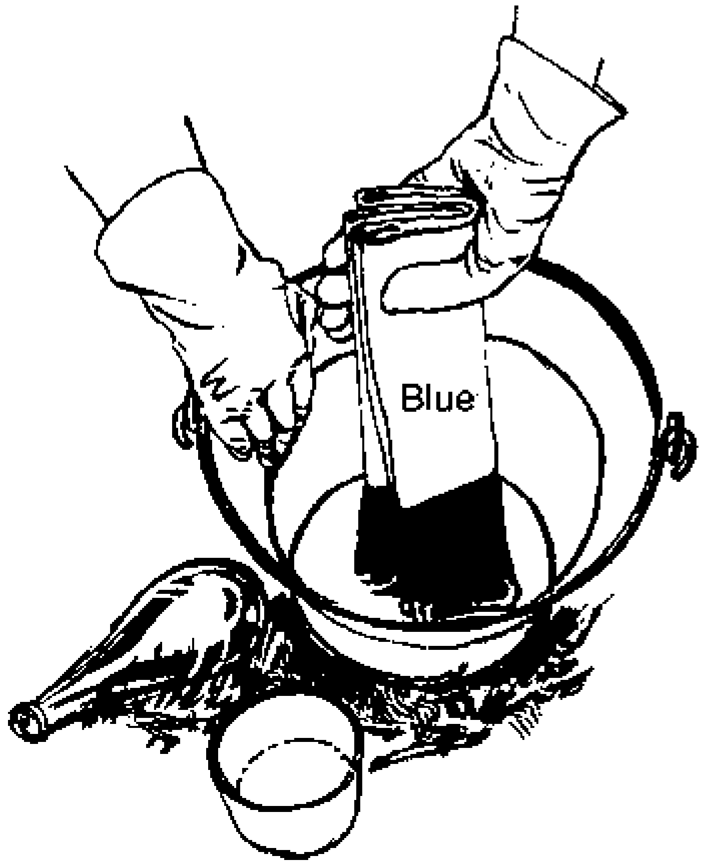


Fig. 2.25. The black part of the screen is soaked in the insecticide mixture.

Fig. 2.26. After impregnation, the trap or screen is spread out on grass or a plastic sheet to dry.

Mix the concentrate with the quantity of water *b* (Fig. 2.24). Put the mixture into a bucket or container big enough for the trap or screen to be soaked in it. Squeeze the trap or screen in the solution until it is completely wet and has absorbed all the solution (Fig. 2.25). The wet trap or screen is then allowed to dry on a surface of plastic or grass (Fig. 2.26). During the whole procedure, gloves should be worn to protect the hands from insecticide.

If the blue and black material of a trap is made of plastic, only the top part, made of mosquito netting, should be soaked. Screens may be folded in such a way that only the black part is soaked.

Delivering insecticide to the community

In large-scale tsetse control programmes with community participation the insecticide can be delivered to individuals as follows:

- Record the number of traps and/or screens to be impregnated by the person. Calculate the quantity of insecticide concentrate required and put it into a standard bottle that is available at low cost.

- Using a template (Fig. 2.27), mark the bottle to indicate the level to which it should be filled with water to obtain the appropriate dilution of insecticide.

The advantage of this system is that people can take the insecticide home and do not have to apply it immediately. Once the insecticide concentrate is diluted in water it must be used within a few hours.

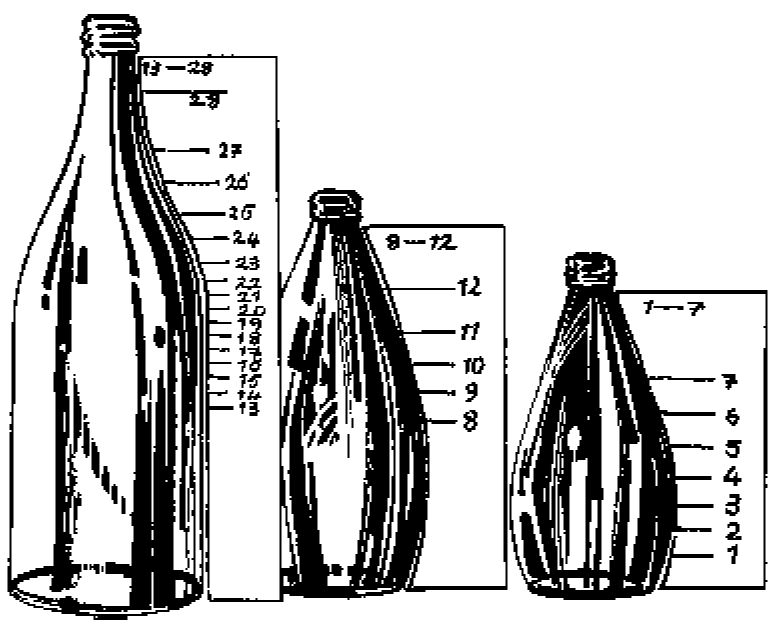


Fig. 2.27. Templates can be made from cardboard or plastic for some commonly available types of bottle.

Fig. 2.28. Traps can be re-impregnated with a spray-on application.

Spraying

In large-scale tsetse control programmes it may be preferable to re-impregnate traps by spraying them in the field (Fig. 2.28). Hand-compression sprayers are suitable for this purpose.

Insecticide spraying

During acute epidemic outbreaks of sleeping sickness it may be preferable to control tsetse flies by ground or aerial spraying of insecticides. Spraying is not generally recommended for routine use because of the high costs, the need for specialized equipment and suitably trained personnel, and pollution of the environment. However, where appropriate, specialized health workers may organize ground spraying with the participation of the community. Pressurized knapsack sprayers are used by farmers in some countries for the control of crop pests and can easily be adapted for use in tsetse fly control.

The aim of spraying is to apply residual insecticide to the daytime resting places of the flies, such as tree trunks, twigs and roots. The insecticide must remain active for at least two months, the duration of the pupal stage, to kill all the emerging flies. Small doses of non-residual insecticides can be sprayed from aerosol cans to kill resting or flying tsetse flies directly.

Ground spraying

Normally only the known resting places are sprayed, to limit the quantity of insecticide used and the amount of work needed. A stretch of vegetation measuring 10 m in width is sprayed from ground level to a height of 0.75-4 m, depending on the species and the location of the treated areas. Applications are carried out during the dry season so that the insecticide is not washed away by rain. The most widely used insecticides have been wettable powder formulations of DDT, dield-rin, endosulfan and, more recently, the synthetic pyrethroids. The pyrethroids have the advantages that they quickly break down in the environment and have a very low toxicity to mammals and humans; they include deltamethrin, alphamethrin, cyfluthrin, cypermethrin and permethrin. DDT, diluted to 50g/litre, and endosulfan, 30g/litre, are sprayed on to the vegetation until the point of run-off is attained.

Equipment

Hand-compression knapsack sprayers (Fig. 2.29), portable motorized sprayers and motorized spray pumps transported on a tractor may be used. The first two sprayers are in use for other purposes by farmers in some countries and can be adapted for sleeping sickness control.

Fig. 2.29. Residual spraying of tsetse resting and breeding sites in vegetation using a hand-compression sprayer.

To avoid wasting insecticide and time it is recommended that advice be sought on dose and timing.

Aerial spraying

Helicopters and fixed-wing aircraft have been used mostly for the control of animal trypanosomiasis. On very few occasions, during outbreaks, they have also been employed for the control of human sleeping sickness. Helicopters are used to apply residual insecticides or non-residual aerosols at selected places. Small aircraft are also used for aerosol spraying at regular intervals.

Because the insecticide particles have to move downwards, spraying can normally not be carried out between 09:00 and 17:00, when there is an upward movement of air. Only in the early morning hours or the late afternoon are atmospheric conditions suitable for aerial spraying. Dense forests should not be sprayed from the air because the insecticide will not reach the lower levels.

Aerial spraying is quicker than ground spraying, but has the important disadvantages of high cost and the need for specialized equipment; another disadvantage is that non-residual aerosol applications have to be repeated five times at intervals of about 10 days. This control method should therefore only be used in emergency situations.

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Chapter 3 - Triatomine bugs

Vectors of Chagas disease

Triatomine bugs are large bloodsucking insects that occur mainly in Latin America and the southern USA. A number of species have adapted to living in and around houses and are important in the transmission to humans of *Trypanosoma cruzi*, the parasite that causes Chagas disease (also known as American trypanosomiasis). Chagas disease, which occurs in most South and Central American countries, is incurable and in its chronic phase may cause damage to the heart and intestines. Some patients eventually die from heart failure. Transmission can be successfully interrupted by controlling the triatomine bugs in and around the houses where they have their resting places.

Biology

Although different *Triatoma* species occur in various countries they are all similar in appearance and life cycle, and are easy to distinguish from other insects (Fig. 3.1). In Latin American countries the bugs are known under a variety of local names, including barbeiros, vinchucas, pitos and chinches.

Life cycle

The total duration of the life cycle of the triatomine bug, from egg to adult, varies from 4 to 24 months, depending on the species and environmental conditions (Fig. 3.2). The most important vector species usually have one or two cycles per year. The adults differ from the immature stages (nymphs) by the presence of fully developed wings and genitalia. The adults and immature stages occupy similar habitats and have similar feeding habits.

Behaviour

The bugs occur in both forested and dry areas in the Americas. The adult and immature stages live in the burrows and nests of wild animals, including birds, bats, squirrels, opossums and armadillos, on which they feed during the night by sucking blood when the animals are asleep. A number of species have adapted to living in and near houses, where they feed on humans and domestic animals, including chickens, cattle, goats, cats and dogs. Feeding may take 10-25 minutes.

Resting places

The triatomine bug species that transmit Chagas disease rest during the day in dark crevices close to their source of blood.

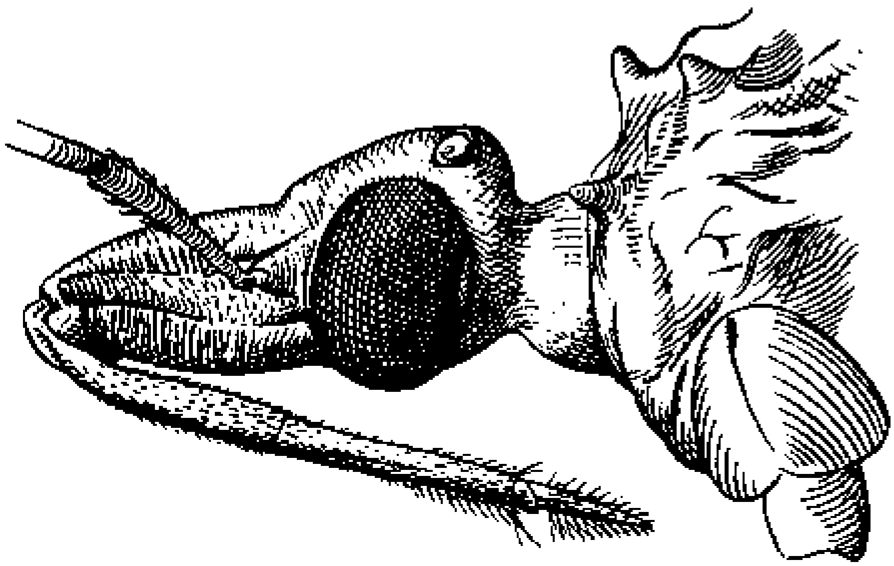


Fig. 3.1. Close-up of the head of a triatomine bug, showing the proboscis (by courtesy of the Natural History Museum, London).

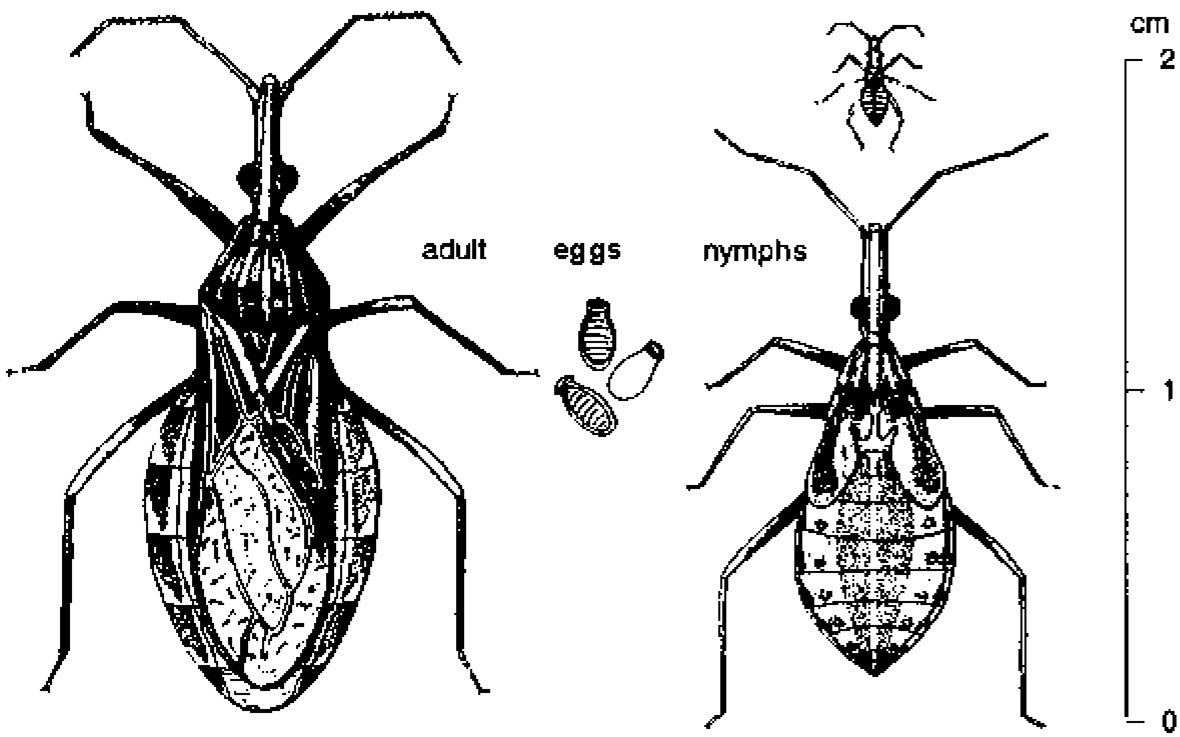


Fig. 3.2. Life cycle of the triatomine bug (by courtesy of the Natural History Museum, London).

Domestic resting places

During daytime the triatomine bugs prefer to hide in dark crevices, which are abundant in unplastered cracked walls of mud or mud-brick. Other hiding places are behind pictures, among furniture, boxes, and clothes hanging from pegs in walls, and in beds (Figs. 3.3 and 3.4). An important vector species, *Rhodnius prolixus*, which is found in

Colombia, Venezuela and Central America, often hides in palm-thatched roofs. *Triatoma infestans*, which is the most important vector species in South America, often hides in roofs of wood and soil (Fig. 3.5). A vector species in Central America, *Triatoma dimidiata*, also hides in cracks in floors.

Peridomestic resting places

Some of the triatomine bug species find suitable resting places in areas surrounding houses, from which they may re-enter houses to feed. Resting occurs in all sorts of stored objects, such as firewood, lumber, tiles, stones and bags of food. Resting bugs are also found in animal quarters, such as chicken houses and goat corrals.

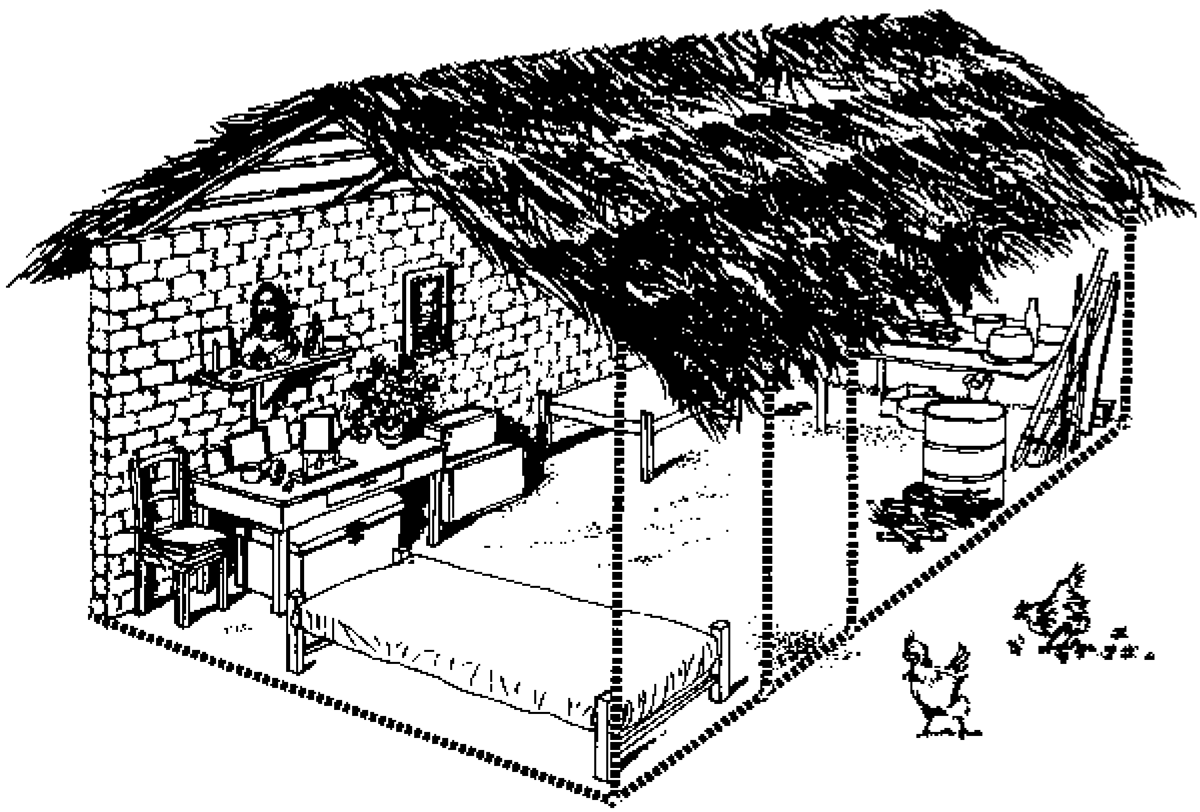
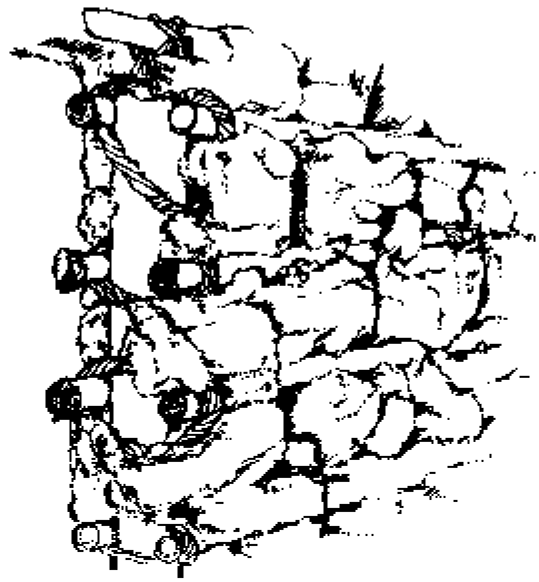
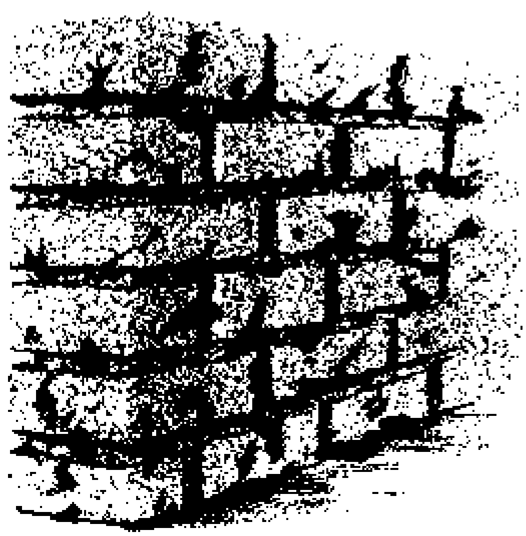


Fig. 3.3. The bugs find suitable hiding places in crevices in mud-brick walls and dark places among boxes, firewood and other objects, behind pictures, in beds and in palm-thatched roofs.

Fig. 3.4. The most important resting places are (a) the deep cracks in walls of mud and wattle or (b) mud-bricks (adobe).



(a)



(b)

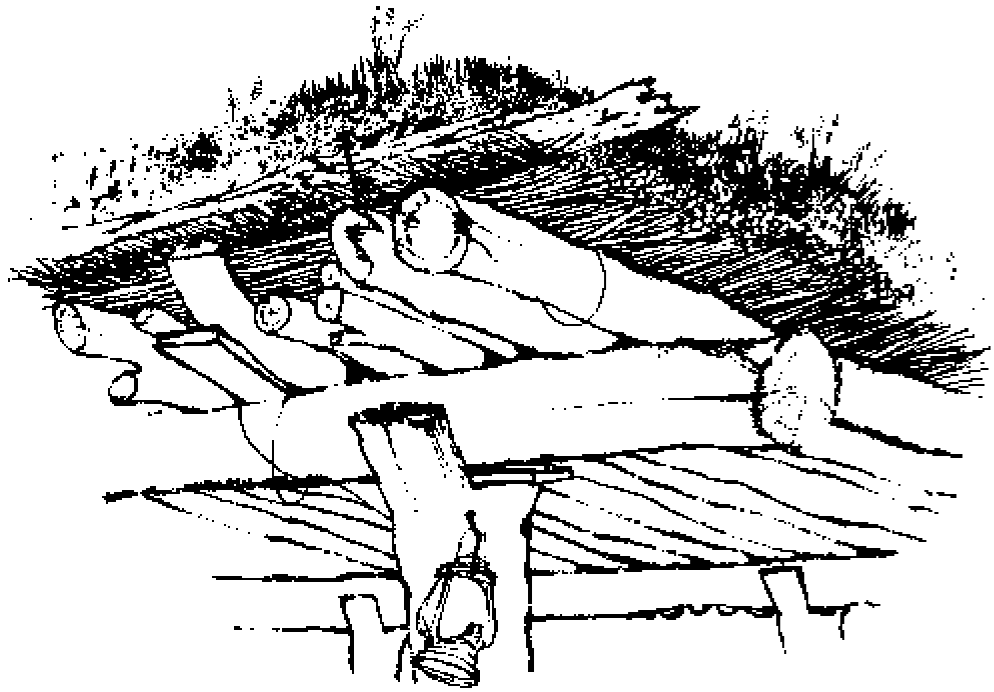


Fig. 3.5. Roofs of wood and soil are important resting places for *Triatoma infestans* in Argentina and Bolivia.

Public health importance

Nuisance

Biting is usually relatively painless and most people are not woken up when it occurs. In some cases severe itching and other skin problems occur afterwards. Large populations of triatomine bugs can cause chronic anaemia through loss of blood (*1*, *2*).

Chagas disease

American trypanosomiasis, or Chagas disease, is caused by a protozoan parasite, *Trypanosoma cruzi*, which is transmitted to humans by triatomine bugs. The disease is associated with poverty in rural areas in Central and South America. In 1996 it was estimated that between 16 and 18 million people were infected, of whom over 6 million would develop clinically overt disease and 45000 would die per year (Fig. 3.6) (*3*).

Transmission

The bugs ingest the parasites when they feed on an infected animal or person. Infected bugs then deposit the parasites with their faeces on the skin of another person during or shortly after feeding. Scratching or rubbing helps the parasites to enter the body through the bite wound or broken skin. Carried by the fingers, they can also penetrate through the mucosae of the eyes, nose or mouth, eventually reaching the bloodstream. The parasites cannot penetrate undamaged skin (Fig. 3.7).

Transmission of the parasite can take place between wild animal reservoirs and bugs without the involvement of human beings. Humans may become infected when they enter the natural environment where infected wild animals and vectors occur. Where these areas become dominated by humans-the reservoir animals being killed or forced out-the bugs may increasingly transmit the parasite to domestic animals and people. The construction of houses and animal shelters provides alternative resting and hiding places for the bugs.

Fig. 3.6. Geographical distribution of Chagas disease in the Americas, 1996 (© WHO).
WHO 96190

Transmission is also possible from mother to unborn child during pregnancy and by transfusion of infected blood. This is an increasingly important problem in some urban areas.

Clinical symptoms

A small sore often develops at the point where the parasite enters the body. If this site is around the eye a marked swelling of the eyelid may develop, known as Romaña's sign (Fig. 3.8); this happens in an estimated 50% of infected people. Some days later fever may occur and the lymph nodes may swell. This stage may be fatal in children, but in most cases the patient survives.

The next phase is without symptoms and may last months or years. However, the parasites invade and slowly affect most organs in the body, and this eventually results in chronic symptoms, such as irreversible damage to the heart and intestines. It is estimated that 27% of those infected develop heart problems which may cause sudden death, 6% develop abnormalities of the digestive system, and 3% show damage to the central and peripheral nervous systems.

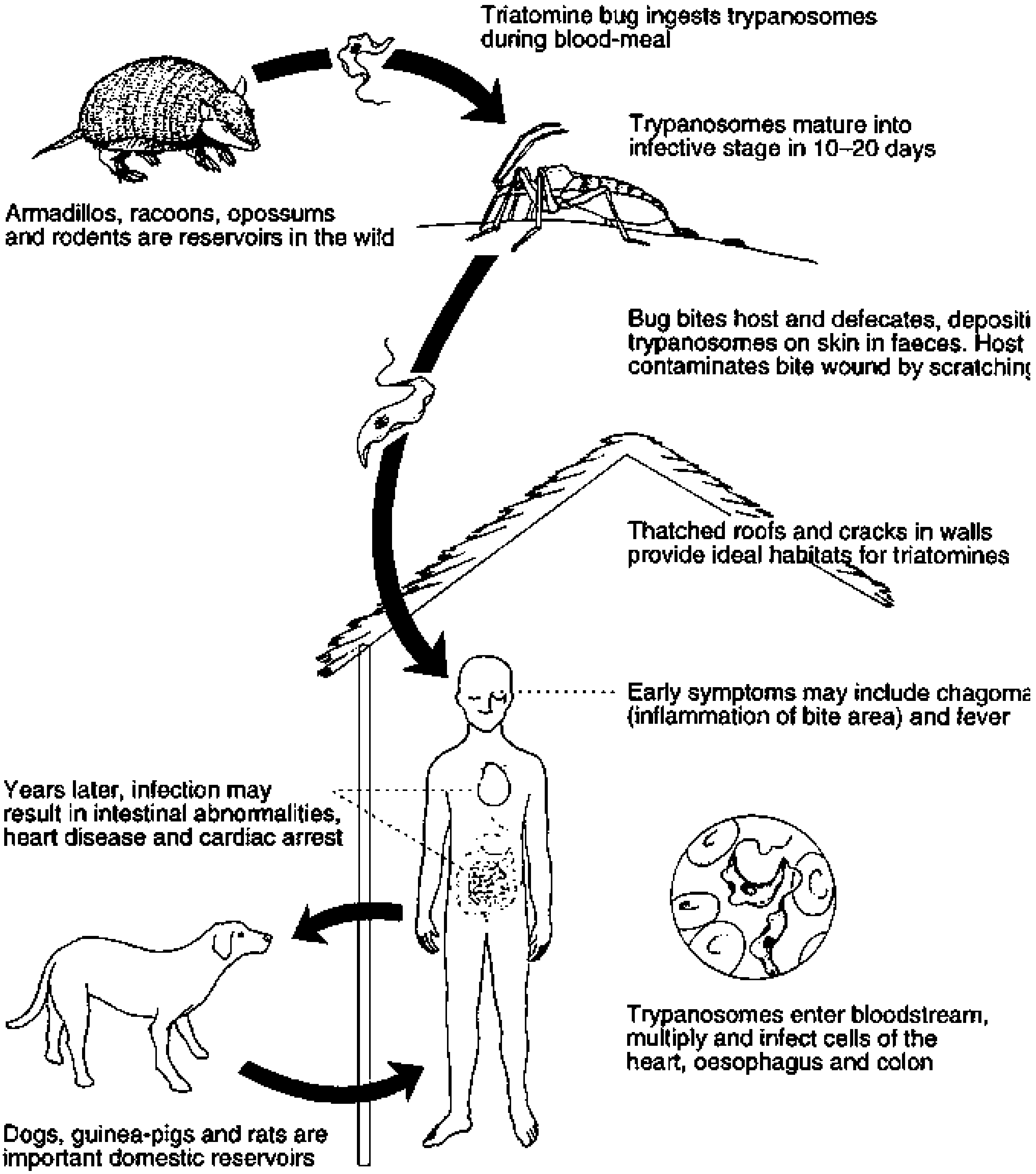


Fig. 3.7. Life cycle of *Trypanosoma cruzi* (by Taina Litwak for the United States Agency for International Development's VBC Project).

Prevention and control

No satisfactory drugs for the treatment of chronic Chagas disease are available. For early infection, which is difficult to diagnose, nifurtimox and benznidazole can be used, although they may cause side-effects. To improve early diagnosis, a network of laboratories has been established in the endemic countries, facilitating field collection of blood samples and ensuring standard criteria for diagnosis.

The avoidance of infection through control of the triatomine bugs is particularly important. The most important methods are:

- spraying of the walls and roofs of houses with insecticides; this is the preferred method in most areas with endemic Chagas disease;

Fig. 3.8. A typical early symptom of Chagas disease is swelling of the eyelid, known as Romaña's sign.

- improvement of houses to reduce or eliminate hiding places; this is the most suitable method for individual self-protection, and is of particular importance in preventing reinfestation where insecticidal spraying has eliminated the bugs.

The transmission of Chagas disease through blood transfusion is being prevented by the development and implementation of special tests to screen blood in blood banks.

Control measures

Recommended control activities differ according to the level of infestation of houses with triatomine bugs and the occurrence of transmission of Chagas disease. Seven countries in which the disease is endemic, namely Argentina, Bolivia, Brazil, Chile, Paraguay, Uruguay and Venezuela, have established national programmes for vector control. These programmes are mostly based on the spraying of walls in houses and the peridomestic resting places with residual, long-lasting insecticides. Specially trained government teams normally carry out the spraying activities, which are divided into preparatory, attack and vigilance phases. During the attack phase, all houses are sprayed in communities where infested dwellings have been detected.

In Brazil, for example, if no more than 5% of the houses in a locality are found to be infested after spraying, it is placed in the vigilance phase. Spraying is interrupted but householders themselves report the presence of bugs (see p. 232). Reinfested houses are then re-treated, together with all surrounding houses.

Good results have been obtained with this approach, but it is expensive. More emphasis is now being given to cheaper methods, the decentralization of control activities, and increased community involvement. Efforts in Bolivia, Brazil and Venezuela have demonstrated that house improvement is also an effective control method (*3*).

In northern Argentina a community-based programme of large-scale distribution of fumigant canisters in combination with the monitoring of surveillance boxes (see p. 234) successfully interrupted the transmission of Chagas disease. However, it is not clear whether this approach could be applied in other areas (*4*).

In the vigilance phase, government action almost ceases and community action is needed to improve housing and the peridomestic environment, carry out surveillance activities, treat reinfested houses, and implement simple methods of self-protection such as the application of insecticidal paint and the use of impregnated sheeting, impregnated mosquito nets and fumigant canisters.

A recent development may significantly change the way in which Chagas disease is controlled: in 1991 the health ministers of Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay adopted a resolution calling for action to eliminate Chagas disease through a combination of vector control measures and blood screening. The intention is to spray every home in areas known to be infested with *Triatoma infestans*. An intergovernmental commission has been appointed to raise and administer funds and to coordinate the plan (*5*).

Application of insecticides to house walls

Triatomine bugs usually make extensive contact with walls and roofs of houses by walking over them at night and hiding on or in them during the day. The application to walls and roofs of an insecticide with a long residual life may kill most of the bugs (Fig. 3.9). Apart from spraying houses, and especially bedrooms, it is recommended that bug habitats in the peridomestic environment be sprayed. If applied correctly, the recommended insecticides have low toxicity for humans.

Insecticide spraying is a specialized skill and operatives need training. Communities may consider having some of their members trained for this purpose. Health workers in medical organizations may also consider this as one of their responsibilities. Untrained people should not try to apply insecticides in their houses since this is likely to result in uneven coverage, wastage, and overexposure of inhabitants to insecticides. Even the safest insecticides should not be applied by hand or without proper precautions. Information on spraying equipment and techniques and on the safe use of insecticides is given in Chapters 9 and 10.

Fig. 3.9. Insecticides are generally applied to walls and roofs by spraying.

Unfortunately, not all wall materials are equally suitable for the application of insecticides. Walls made of non-porous materials such as tropical hardwood, painted wood, and compressed or fire-baked bricks, and walls covered with plaster, are the most suitable since the insecticide will remain on the surface. Porous materials such as mud absorb much of the insecticide applied. Moreover, minerals in mud and whitewash on plaster may rapidly degrade conventional insecticide formulations. The activity of an insecticide may last a year or more on timber walls but less than 2-3 months on adobe.

Insecticides

DDT is not sufficiently effective against triatomine bugs. More expensive insecticides, such as dieldrin, benzene hexachloride (BHC) and propoxur have been used. Their residual activity on mud walls does not generally last for more than three months. Nowadays the insecticides of choice are mainly synthetic pyrethroids, such as cypermethrin, cyfluthrin, deltamethrin, permethrin, lambdacyhalothrin and fenpropathrin. Although often more expensive than previously used insecticides they tend to have much longer residual activity, are applied in lower dosages, and are thus more cost-effective (*6*).

Wettable powders and suspension concentrates are suitable formulations for spraying on porous wall surfaces. Their residual efficacy is longer than that of emulsifiable concentrates because the insecticide particles are larger and do not penetrate into wall surfaces but remain available for contact with insects.

Slow-release formulations (insecticidal paints)

These formulations seem to cope with the problem of quick degradation of insecticide on mud surfaces as well as with absorption. They are based on latex or polyvinyl acetate and can be applied to walls by spraying or brushing (Figs. 3.10 and 3.11).

Application of the paint by brushing has the advantage of being simpler and cheaper than conventional insecticide application, taking into account the long persistence of the products. However, mud walls are not very suitable for brushing, which erodes the surface; spraying covers the surface with a thin film and is preferred by vector control agencies because it is less time-consuming and more efficient.

Recently an insecticidal paint effective against triatomine bugs has been specially developed for spraying on mud surfaces (*7*, *8*). It is also suitable for brush-on application. After drying it becomes transparent and produces a thin plastic film.

This product has to be mixed with water before application.

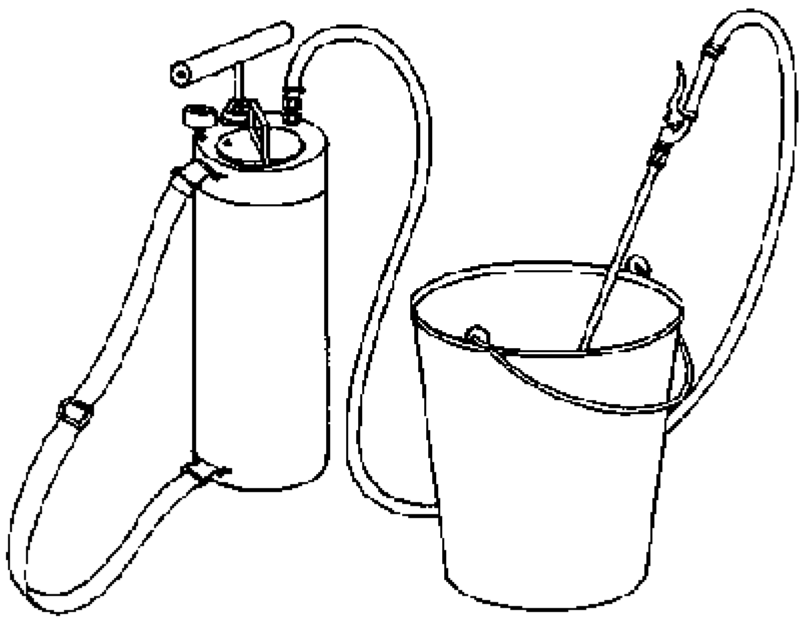


Fig. 3.10. Insecticidal paint can be sprayed on to surfaces. The filter in the handle grip has to be removed to avoid polymerization of the latex. Between applications the nozzle should be kept under water and at the end of a spraying operation the equipment should be carefully cleaned with water.

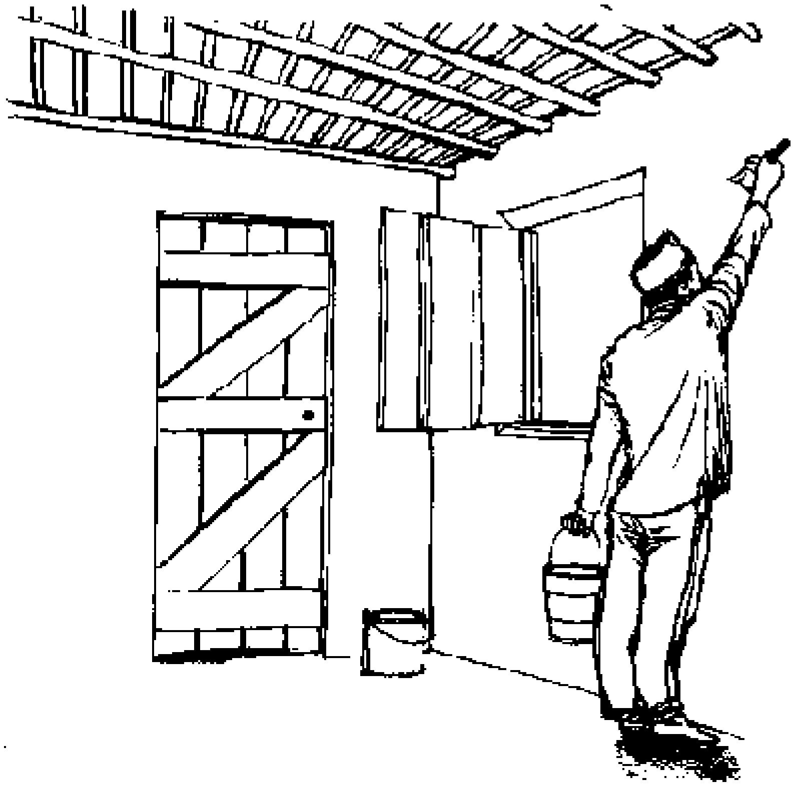


Fig. 3.11. Slow-release insecticidal paints are suitable for brush-on application.

Composition of insecticidal paint

Only insecticides with a high vapour pressure can be used, because the particles have to move to the surface of the paint layer. Malathion, propoxur, pirimiphos methyl and fenitrothion are suitable. Thus 8.3% malathion emulsifiable concentrate or wettable powder added to an emulsi-fiable suspension consisting mainly of polyvinyl acetate, after drying, leaves a thin film containing around 13% of active ingredient that continuously migrates to the surface.

Advantages and disadvantages of insecticidal paints

Advantages

- The insecticidal paints have greater persistence and therefore better cost-effectiveness than conventional insecticides. One application may last up to two years, whereas standard formulations of insecticides such as the synthetic pyrethroids and BHC do not last longer than a year. In a study in Brazil the cost of keeping a house free of triatomine bugs for one year was estimated at US$29 for paint, $73 for BHC, and between $31 and $66 for most common pyrethroids.

- The paints are appreciated by house owners because they make mud walls more resistant to abrasion.

Disadvantages

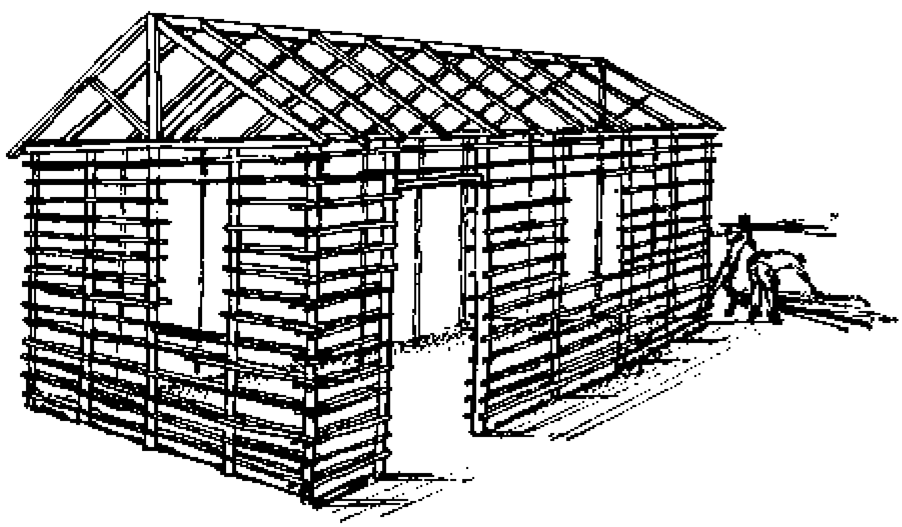
• A larger quantity of formulation has to be transported per house and precautions have to be taken to prevent blockage of spray nozzles by the polymerizing latex.

Coating house frames with insecticide-impregnated paint[a]

[a] For more information, contact Nucleo de Pesquisas de Produtos Naturais, Federal University of Rio de Janeiro, CEP 21941, Rio de Janeiro, Brazil.

In constructing a mud-and-wattle house, before the wooden frame is filled with mud, it can be painted with a slow-release insecticidal paint (Fig. 3.12). Any cracks that appear at a later stage will offer toxic resting places to the bugs.

Fig. 3.12. Insecticidal paint can be applied to the wooden frame of a mud-and-wattle house.



(a)

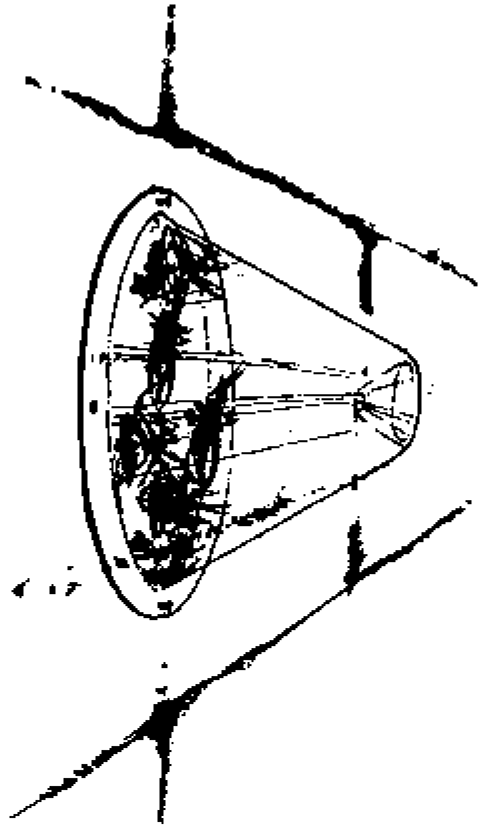
(b)

The most important requirement for a paint to be applied on the wood is a long residual effectiveness because reapplication is impossible. A paint made of oxidized bitumen and an organophosphorus compound such as malathion or chlorpyriphos seems to be most suitable. In laboratory and field experiments (*7*, *8*) it remained toxic for at least five years. When used for this purpose the unattractive black appearance is of no importance.

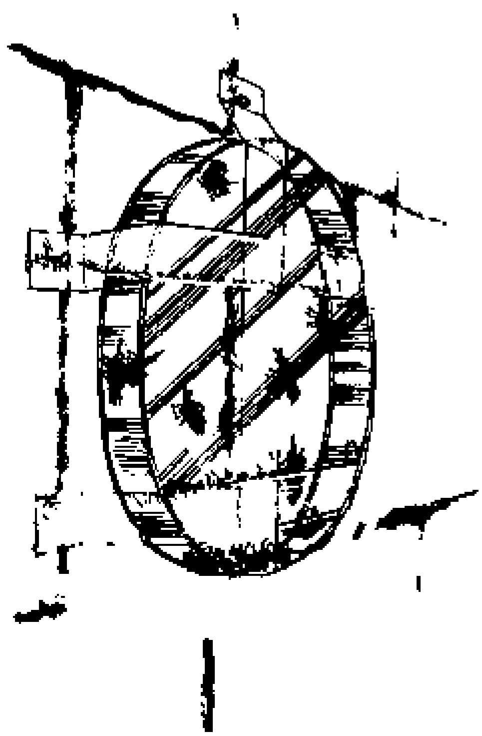
Determination of residual activity

A simple test can detect loss of residual activity of an insecticide over time. For one test about ten adult bugs or nymphs should be collected (preferably recently-fed fifth-instar nymphs) and exposed for a fixed time to the surface area under investigation. They should be confined beneath a standard WHO bioassay cone or an inverted glass Petri dish (or any other flat transparent container) attached to the treated surface with elastic bands, tape, nails or other suitable means (Fig. 3.13). The container should preferably be placed on a flat surface without cracks to prevent the bugs from escaping. If this is impossible the cracks should be filled and the container sealed to the wall surface. Large fifth-instar bugs or adults are preferred because they are the least susceptible to insecticides and can less easily escape through small openings. For purposes of comparison the same kind of surface should be used in each test.

Fig. 3.13. A loss in residual activity of insecticide on a wall can be detected by exposing triatomine bugs to the treated wall surface under a standard WHO bioassay cone (a) or, for example, an inverted Petri dish (b).



(a)



(b)

Bugs for testing can be obtained from vector control agencies and research institutes or by collection in the field. Be very careful to avoid contact with the faeces of wild bugs because they may be infected with the parasites that cause Chagas disease.

The period of exposure can last from several hours to several days. The duration should be chosen in a test conducted shortly after the insecticide has been applied, such that a mortality of between 90% and 100% among the exposed bugs is achieved. After the exposure period, the bugs should be held for 1-3 days in a cup (Fig. 3.14). The cup should be kept in a cool place and should contain a piece of paper to absorb excrement. At the end of this period, the final mortality is recorded. When a test shows a significantly lower mortality than a previous identical test-say 60% compared with 100%-the insecticide is no longer sufficiently effective.

House improvement

Long-term protection from bugs can be achieved by modifying houses and their immediate surroundings in such a way that resting places are no longer available to the bugs (*9-11*). Inexpensive methods are available to improve walls, roofs and floors (*12*). However, bugs coming from surrounding infested houses or the peridomestic environment may continue to find suitable resting places in boxes, behind pictures and so on. House improvement is therefore more effective if carried out simultaneously by most people in a given area (Fig. 3.15).

Existing houses

Walls

Walls can be improved by filling cracks with plaster prepared from locally available materials (Fig. 3.16). Special attention should be given to filling the cracks at the tops of walls, just below roof level.

How to prepare plaster

1. Mix sand (6 parts), sieved earth (1 part), cow dung (1 part) and lime or cement (0.5-1 part). The lime can be prepared by heating locally collected limestone rocks in an open wood-fired kiln for 24 hours, then pulverizing the white residue with a hammer and mixing it with water. After plastering, the walls can be painted to improve their appearance with, for example, a whitewash of lime and water.

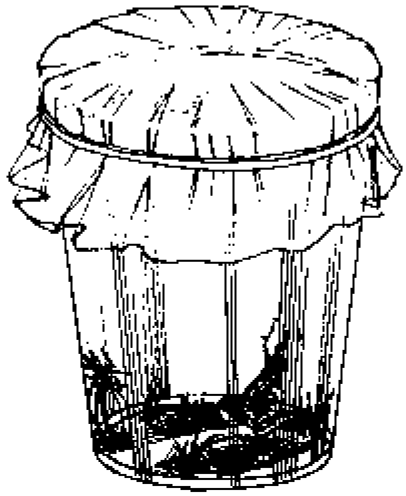


Fig. 3.14. After exposure the bugs are placed in a holding cup for 1-3 days to assess mortality.

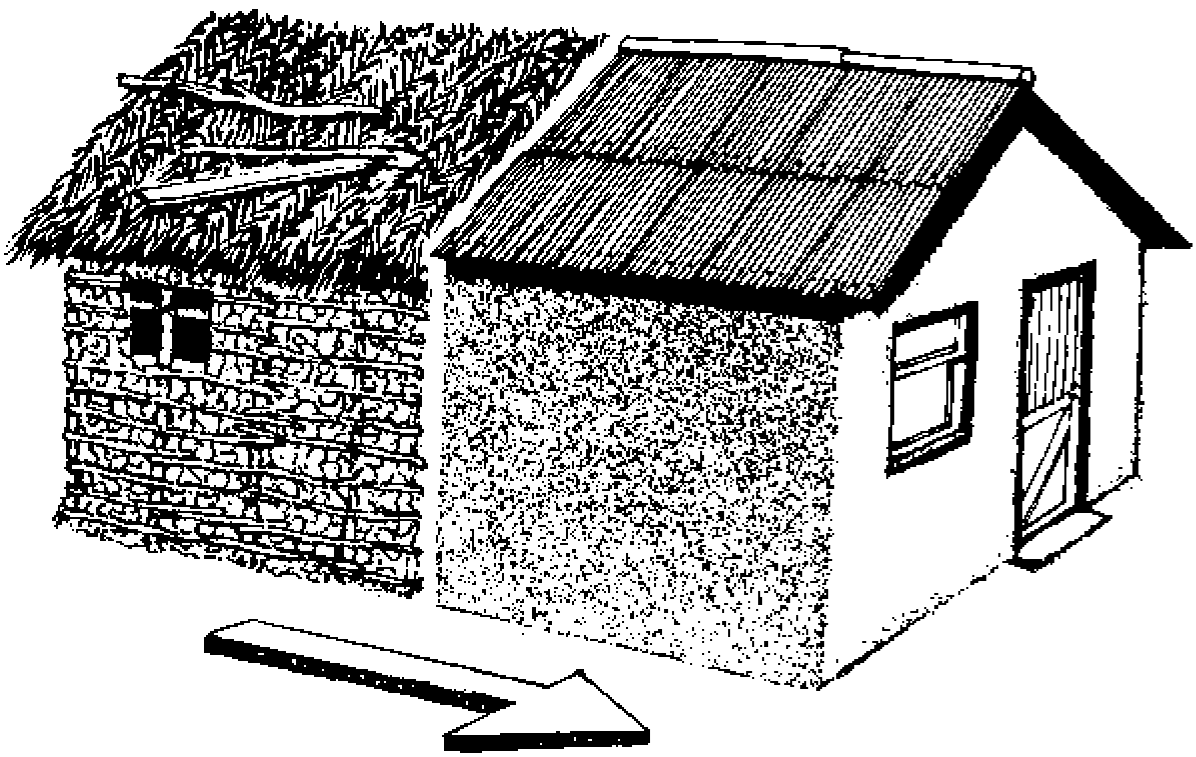


Fig. 3.15. House improvement reduces the resting places available to triatomine bugs.

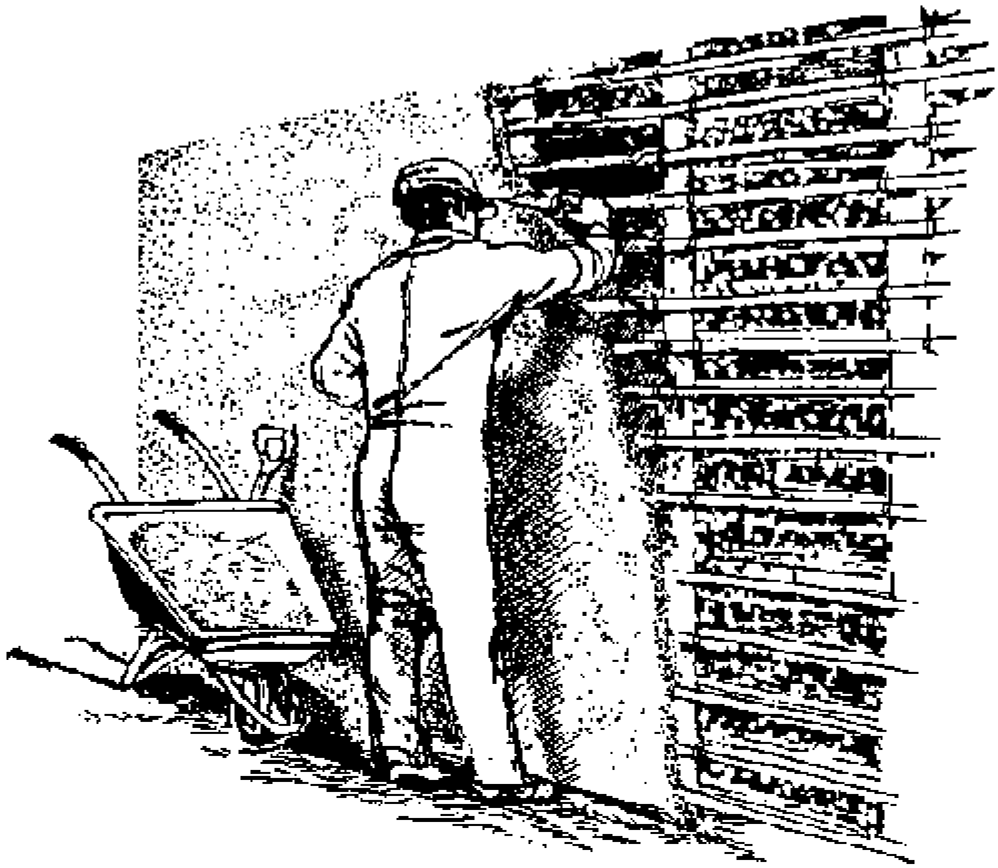


Fig. 3.16. Resting places in walls can be filled with plaster, which can be applied by hand and smoothed by hand or with a trowel.

2. Prepare a mixture of mud and, for strength, very short pieces of straw. Apply a layer of this material to the wall and make sure the entire wall surface is completely smooth. If a thick layer is needed, it is advisable to apply the mud and straw mixture in two or even three thin layers to avoid cracking. Each layer should be allowed to dry before the next one is applied. However, for better adherence the surface should be wetted before another layer is applied (Fig. 3.17).

Cement plaster

So as to improve durability a final layer of concrete should be applied, i.e. a mixture of cement, sand and water. As before, this layer should be applied to a wetted surface for better adherence and should be wetted periodically to prevent cracking.

Cement plaster may become detached if:

- the wall is not wetted before plastering;
- the plaster is not wetted to slow down drying;
- the plaster is of poor quality, i.e. contains too little cement.

Wire reinforcement

Additional strength may be provided to cement plaster by adding wire netting (chicken or fencing wire) (Fig. 3.18). Ideally the wire reinforcement should be used on all walls but priority should be given to those most exposed to rain.

Attach the wire netting before the layer of cement is applied. For the greatest possible strength the netting should be in the middle of this layer. Direct contact between mud plaster and netting may cause the latter to corrode rapidly.

Floors

Especially in Central America where *Triatoma dimidiata* is a vector, floors should be included in house improvement. This could involve smoothing floor surfaces, compacting them and covering them with a layer of cement (Fig. 3.19). Cracks that appear subsequently should be filled.

Fig. 3.17. The surface has to be wetted before the next layer of plaster is applied, in order to improve adherence and prevent cracking caused by excessively rapid drying.

The roof

In areas where traditional roofing materials provide hiding places for bugs (thatched roofs in Venezuela, roofs of wood and soil in Argentina and Bolivia), it is best to replace them by tiles or sheets of corrugated iron.

Tiles have the advantage that, like the traditional roof materials, they insulate houses against heat or cold and look more attractive than corrugated iron; furthermore, they can also be produced locally. However, tiles are heavy and require special construction of roof timbers to carry the load (Fig. 3.20).

Corrugated iron roofs offer the advantage of being widely available and relatively cheap (Fig. 3.21). Fitting the sheets is easy. However, they do not insulate houses against heat or cold and are noisy in heavy rain.

Another roof material is *acerolitos*, a sandwich construction of two layers of aluminium foil with asphalt between. Sheets of this material offer good insulation against temperature extremes but are more vulnerable to damage and more expensive than corrugated iron. Fibre-reinforced cement sheets offer similar advantages but they are heavier and more vulnerable to damage.

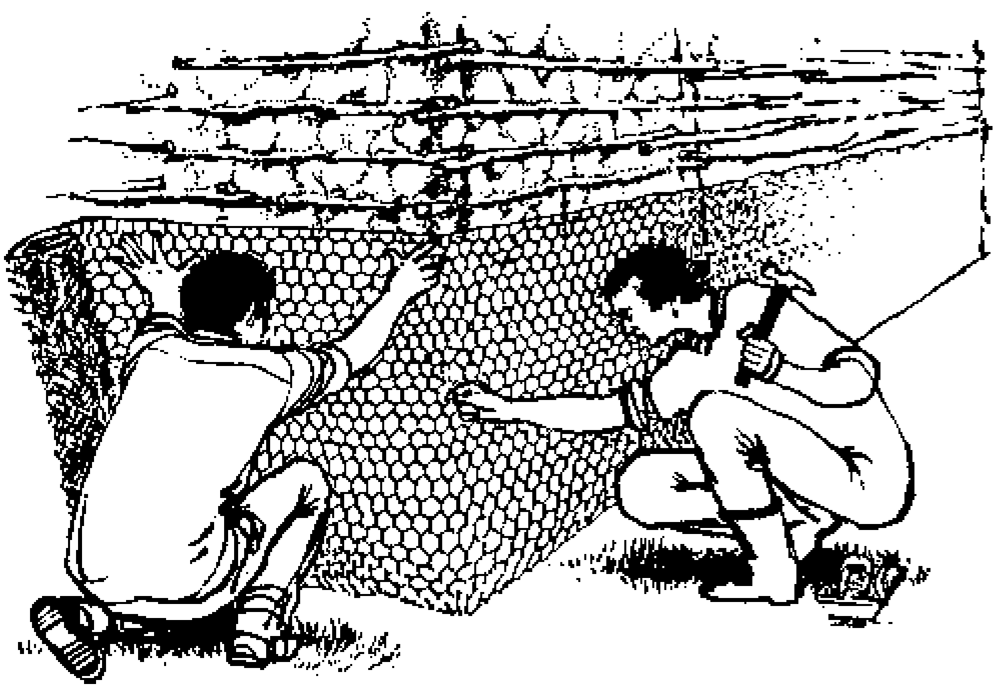


Fig. 3.18. Cement plaster can be reinforced with wire netting.

Fig. 3.19. Resting places in floors can be filled and covered with a layer of cement.

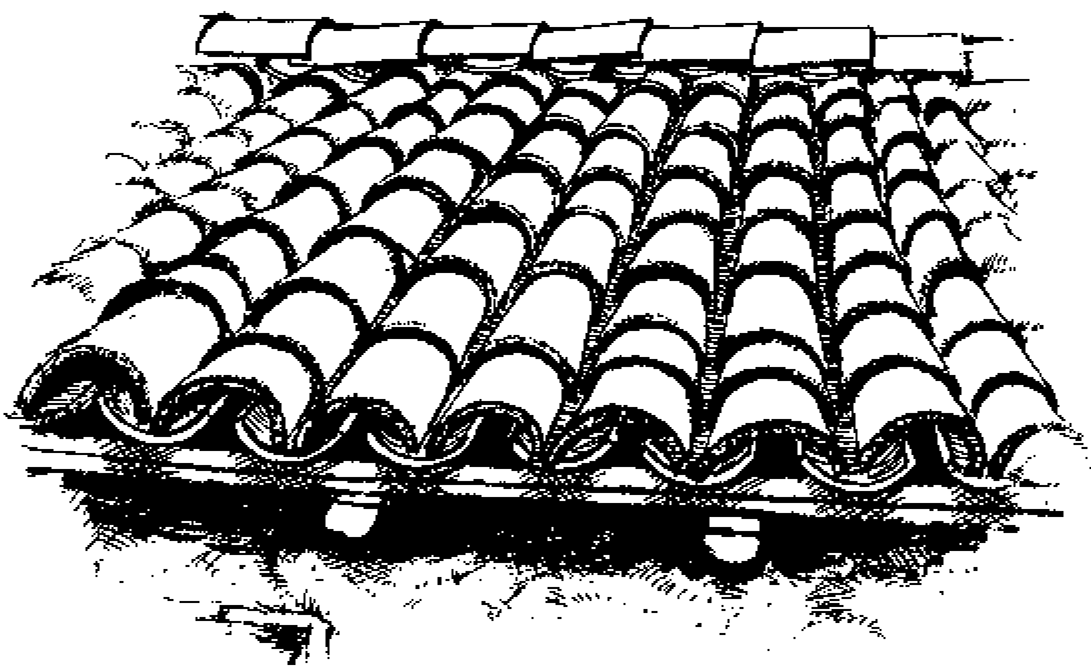


Fig. 3.20. Tiles are a suitable traditional roofing material for the improvement of houses.

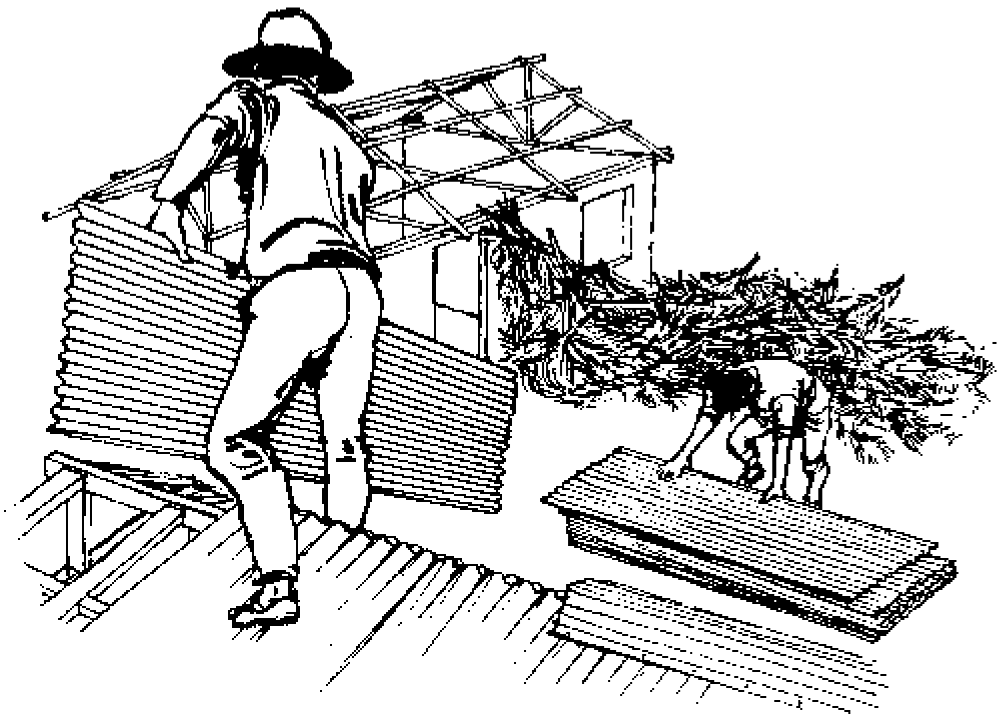


Fig. 3.21. Corrugated iron sheets do not offer a suitable habitat to triatomine bugs.

New houses

Where a new house is to be built or an old one is not worth improvement by the methods described above and has to be replaced, it is recommended that durable materials such as cement, fire-baked bricks or timber be used. If these materials are unavailable or too expensive, it is possible to avoid cracking of mud walls: the earth can be stabilized against erosion and shrinkage by the addition of bitumen (asphalt), cement, lime or straw, or a combination of these materials.

In some areas the traditional sun-dried, unbaked blocks of adobe are already of good quality because of the addition of straw and because of naturally occurring elements in the local soil.

Pressed stabilized soil blocks

High quality mud blocks that are more durable than ordinary blocks and can support more weight can be made by compaction in a mechanical press (Fig. 3.22). The blocks are made at the building site, and this greatly reduces the amount of materials to be transported. Very strong and water resistant, stabilized soil-cement blocks can be made by compacting a mixture of cement (about 5-8%) and soil. Blocks of similar strength can be made by using 7-10% lime. The soil should be dry enough to be crushed to pass through a 6-mm mesh sieve. This is necessary to ensure effective mixing with the cement, which should ideally coat all the soil particles. The soil should preferably contain 5-30% clay. The blocks have to be left to cure for 2-3 weeks before being used (Fig. 3.23). They should be stacked in piles 3-5 days after being pressed, and covered to protect them from rain.[1]

[1] Further information is available from the Building Research Establishment, Garston, Watford, England.

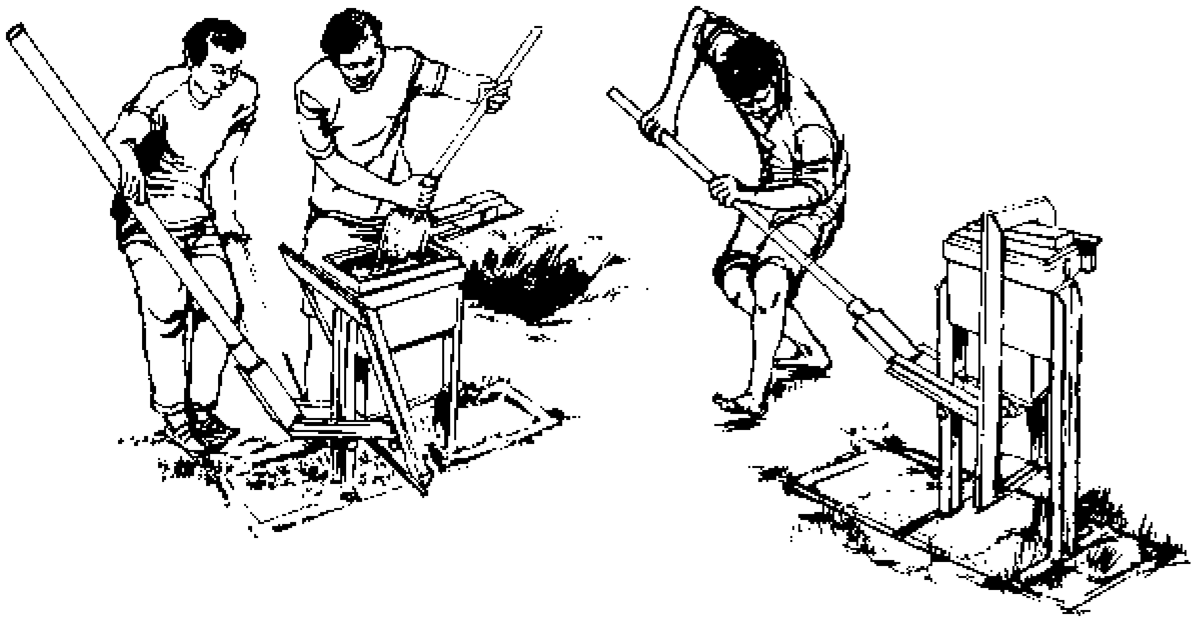


Fig. 3.22. High-quality building blocks can be made by compacting soil under pressure in a mechanical press.

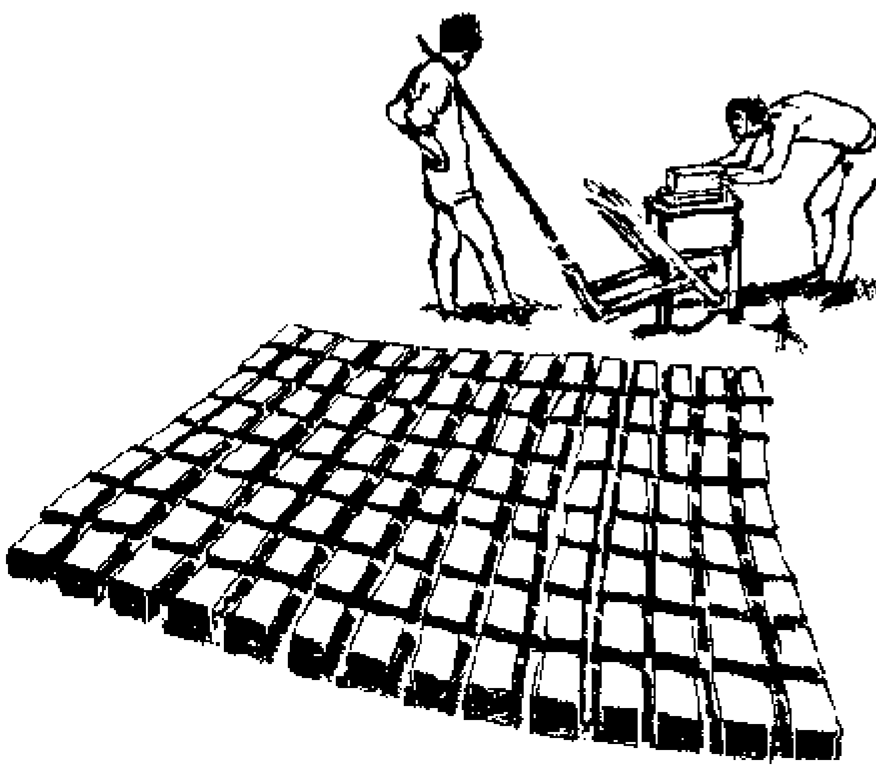


Fig. 3.23. Blocks produced by mechanical presses have to be cured for 2-3 weeks before being used.

Pressed and stabilized blocks can be left unplastered, as the blocks should remain crack-free. Mortar joints should be filled completely and flush-pointed to ensure the absence of voids that could serve as habitats for the bugs.

For low-cost construction the press can be used to make sun-dried blocks of soil without the addition of cement. In this case further improvement can be achieved by plastering the walls with cement; the brick walls should be wetted before plastering.

The press can be operated by one person; with a crew of three or more the machine can be run continuously while the digging and mixing of soil and the stacking of new blocks is going on. Depending on the type of machine, a three-person crew can produce at least 20 blocks an hour. Several types of hand-operated presses have been developed.

Advantages and disadvantages of pressed stabilized soil bricks as compared with ordinary sun-dried mud bricks or mud-and-wattle

Advantages

- Durability, longer life of houses.
- Better appearance.
- Fewer cracks in walls which could offer hiding places to insects.
- Better surface for painting and plastering.
- Because the blocks are less porous than adobe, they offer a suitable surface for spraying of residual insecticides against bugs or malaria mosquitos.

Disadvantages

- Although suitable for individual use the press has to be bought and used by community cooperatives or small-scale business enterprises to make it economically viable.
- Soil preparation is tedious.

Improvement of the peridomestic environment

Fences, roofs and wall constructions of animal shelters and storage places for agricultural products and firewood can be modified so that triatomine bugs do not easily find suitable hiding places in them (Fig. 3.24) (*13*).

Impregnated mosquito nets

Mosquito nets can provide a physical barrier between bloodsucking insects and sleeping persons. However, if not properly tucked in under the mattress or if it has holes that allow insects to enter and feed, the net will be ineffective. Even when a net is properly used, the body may make contact with it, thus allowing the insects to feed.

In addition, mosquito nets are not effective against bloodsucking insects that live in mattresses, such as bedbugs (*Cimex*) and triatomine bugs. Hungry bugs can survive for long periods and are likely to persevere until they manage to feed.

Impregnation of the net with a quick-acting pyrethroid insecticide should prevent these problems. The use of impregnated mosquito nets results in the killing of bedbugs, lice and fleas, as well as mosquitos (Fig. 3.25). Although the effectiveness of this method against triatomine bugs is still under investigation, it is likely that they will be killed or repelled, especially the more vulnerable nymphal stages.

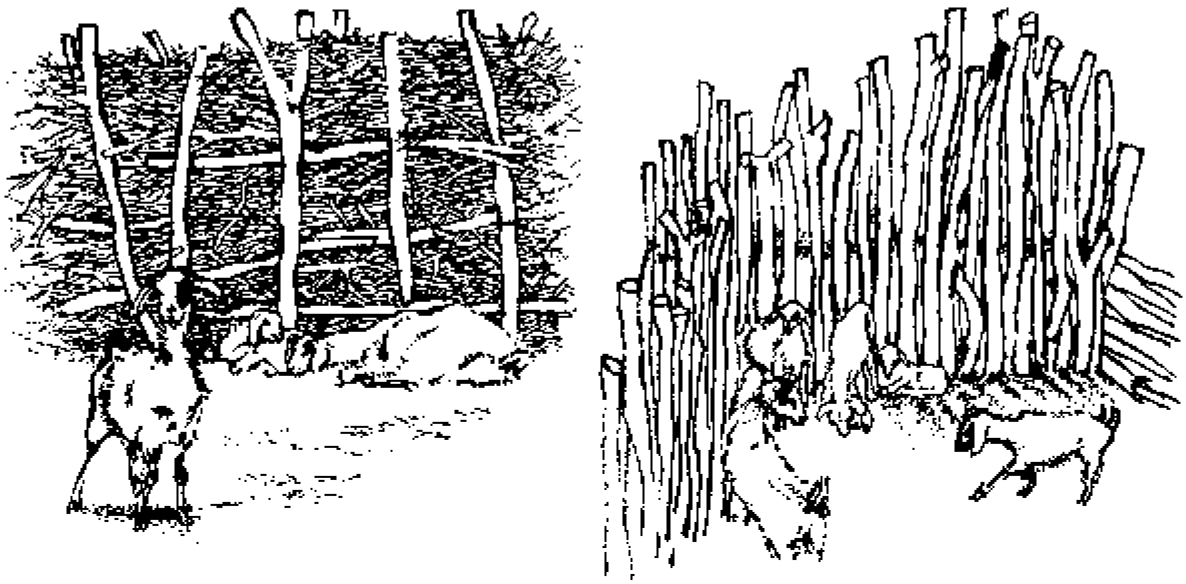


Fig. 3.24. Fences for goat corral. The fence on the right has fewer hiding places for bugs than the one on the left.

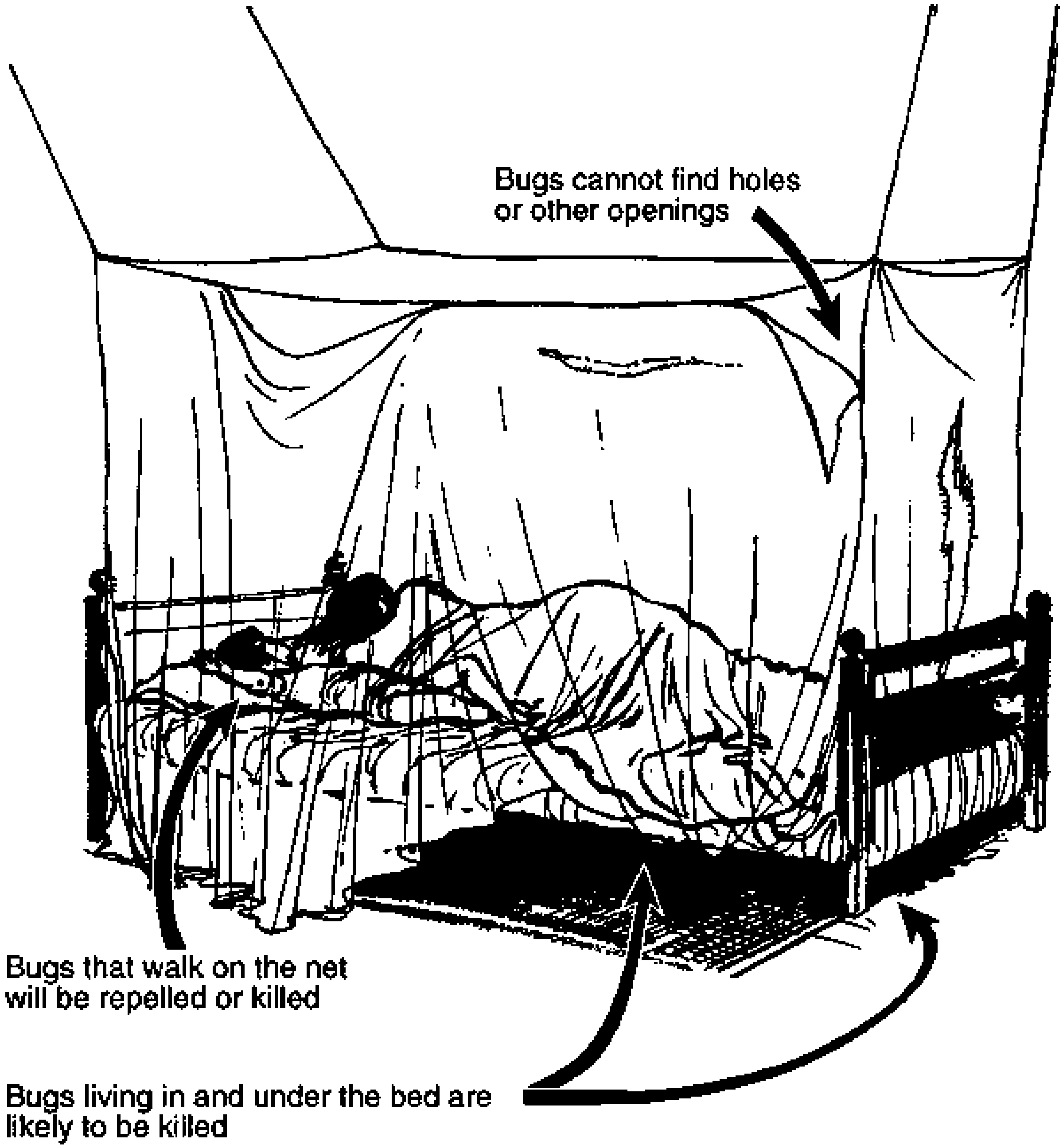


Fig. 3.25. Advantages of mosquito nets impregnated with an insecticide.

Impregnated mosquito nets might be useful for self-protection in areas where no official control activities are carried out. In addition, they could be part of a programme based on community participation aiming to maintain the results obtained by government campaigns. They are not intended as alternatives to wall-spraying or house improvement.

Chapter 1 provides more information on mosquito nets and how to impregnate them with an insecticide.

Fumigant canisters

Disposable fumigant canisters consist of small cans of insecticide, with a fuse sticking out from the top (Fig. 3.26). When the fuse is lit, insecticidal smoke is released for a short period (Fig. 3.27). One can is sufficient for the fumigation of about 15 m^3 of air. Thus a room of 3 x 5 x 2 m = 30 m^3 would need two canisters. In general there should be about two canisters for each room where people or animals sleep. For optimum smoke dispersal the doors between rooms should be left open. During fumigation the gases should penetrate into the hiding places of the bugs. Irritated bugs leave their hiding places and may be killed. For maximum effectiveness all openings of houses should be closed. An hour after a canister has been lit the house can be ventilated and re-entered.

Fumigant canisters may be appropriate in areas where triatomine bugs have been successfully controlled and where house-spraying is no longer carried out on a routine basis. If houses are reinfested, they and the houses immediately surrounding them can be treated quickly and cheaply in this way (*14*).[1]

[1] Information on the availability of fumigant canisters can be obtained from Pest and Insecticide Research Centre (CIPEIN), Zufriategui 4380, Buenos Aires, Argentina.

Advantages and disadvantages of fumigant canisters

Advantages

- The use of canisters does not require special training.

- The method works best in combination with other control methods. In Argentina it has allowed the frequency of house-spraying to be reduced from twice a year to once a year during the surveillance period.

Disadvantages

- The residual activity is short. Bugs may reappear in a treated house within a few months.

- If repeated frequently, the method is expensive.

Use

- The can has to be lit on a fire-resistant surface on the floor away from flammable objects.

Fig. 3.26. After being lit, fumigant canisters produce a smoke that kills insects.

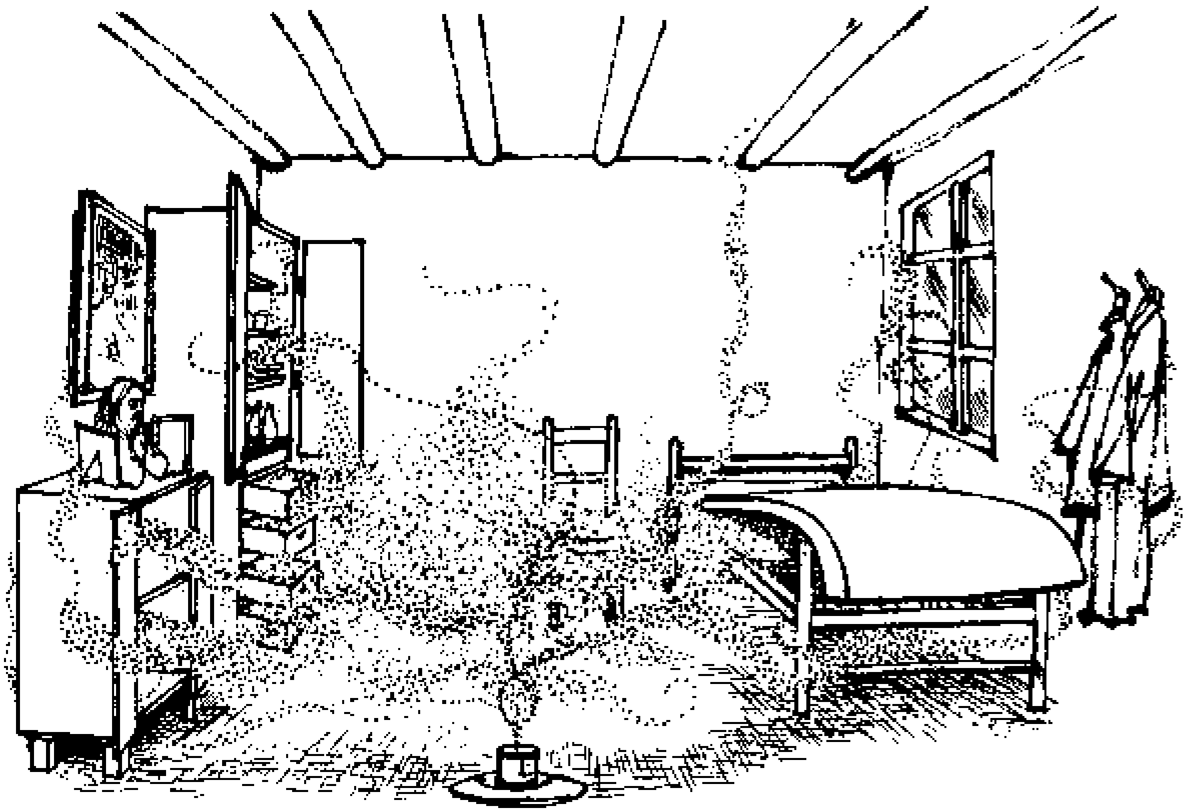


Fig. 3.27. The fumigant canister burns for up to 15 minutes.

- Windows and external doors should be closed and food, drinks and animals removed.
- Cupboards with clothes and other potential hiding places for bugs should be opened.
- Doors between rooms should be opened.
- After lighting the cans, wait at least an hour before re-opening the doors and windows for ventilation.
- Allow the house to ventilate for 30 minutes before re-entering.

Safety

The vapour released from the canister contains insecticides (e.g. dichlorvos, lin-dane and pyrethroid) of very low toxicity to mammals, birds and humans. The method is considered safe for the user. However, during the process of fumigation, people should leave their houses and return only after ventilation has continued for about 30 minutes (with doors and windows open).

The risk of setting fire to houses is very slight since the combustion occurs without a flame.

Surveillance

In areas where large-scale vector control activities with residual wall-spraying have been successful in suppressing or eradicating triatomine bugs it is important to keep a lookout for their reappearance in houses. This would be a signal for either the house owners or the responsible authorities to take action.

Three different strategies can be distinguished for the organization of surveillance activities:

- The government control programme puts special field inspectors in charge of surveillance in certain areas (*15)*.

- Some members of the community are provided with materials and trained to carry out surveillance. They keep the government control programme informed. For example, schoolchildren may be asked to collect the bugs and take them to a teacher, who sends them to the health authorities.

- As part of the primary health care approach, some community members are trained as health workers, and they are in charge of surveillance and retreatment activities, among other things (*16)*.

The first strategy is the most expensive. The third requires the presence of a well organized primary health care system. It is essential that communities and individual house owners participate in surveillance activities. The health authorities should provide information and educational materials, posters and brochures to motivate communities to participate. Community surveillance, if properly organized, saves the authorities much work and money and is likely to improve the quality of control operations.

Surveillance methods

Collecting by hand

The most direct method of detecting bug infestations is to check potential hiding places with a flashlight (Fig. 3.28). Deep crevices and other hiding places can be sprayed with an irritant substance or flushing-out agent, such as a 0.5% solution of a synthetic pyrethroid or pyrethrum in kerosene, to drive out the bugs (*17*, *18*). The spray can be applied with a hand-held plastic spray-gun of the type used for spraying house plants (Fig. 3.29). Any bugs and eggs should be collected with forceps and taken to a teacher or health worker who can identify the species and contact a vector control officer.

Fig. 3.28. Cracks in walls and other potential hiding places can be checked for the presence of bugs.

Fig. 3.29. Deep cracks and crevices in walls may be sprayed with an irritant or flushing-out agent to drive the bugs out of their hiding places.

Surveillance boxes

A less laborious but less precise method involves the use of cardboard boxes that offer hiding places to the bugs. The boxes can be disassembled easily and examined at regular intervals-for example once a month-for bugs, eggs or streaks of faeces on paper or cardboard inside the boxes. Various kinds of box have been designed and tested (*16*, *19*). All are flat and have holes in the sides or bottom and folded paper or cardboard inside (Fig. 3.30). The boxes are nailed to walls at a height of 1.5 m and close to beds, and out of reach of children (Fig. 3.31).

On inspecting the boxes it is important to draw a circle round any faecal streaks to prevent confusion between different observations (Fig. 3.32). Any bugs present should be put in a plastic bag, matchbox or other container and sent for examination to teachers or the health authorities.

Since other insects, such as cockroaches and bedbugs, might also use the boxes as a hiding place, it is important to be able to recognize triatomine bugs and their eggs and faeces. Keys for the determination of the origin of faecal deposits have been published elsewhere (*20*, *21*).

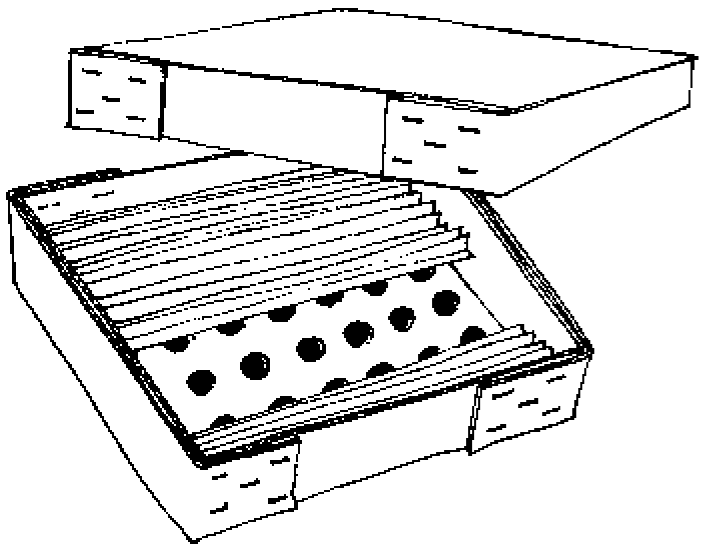


Fig. 3.30. A surveillance box. In the bottom are holes that allow the bugs to enter. Pleated paper provides attractive hiding places.

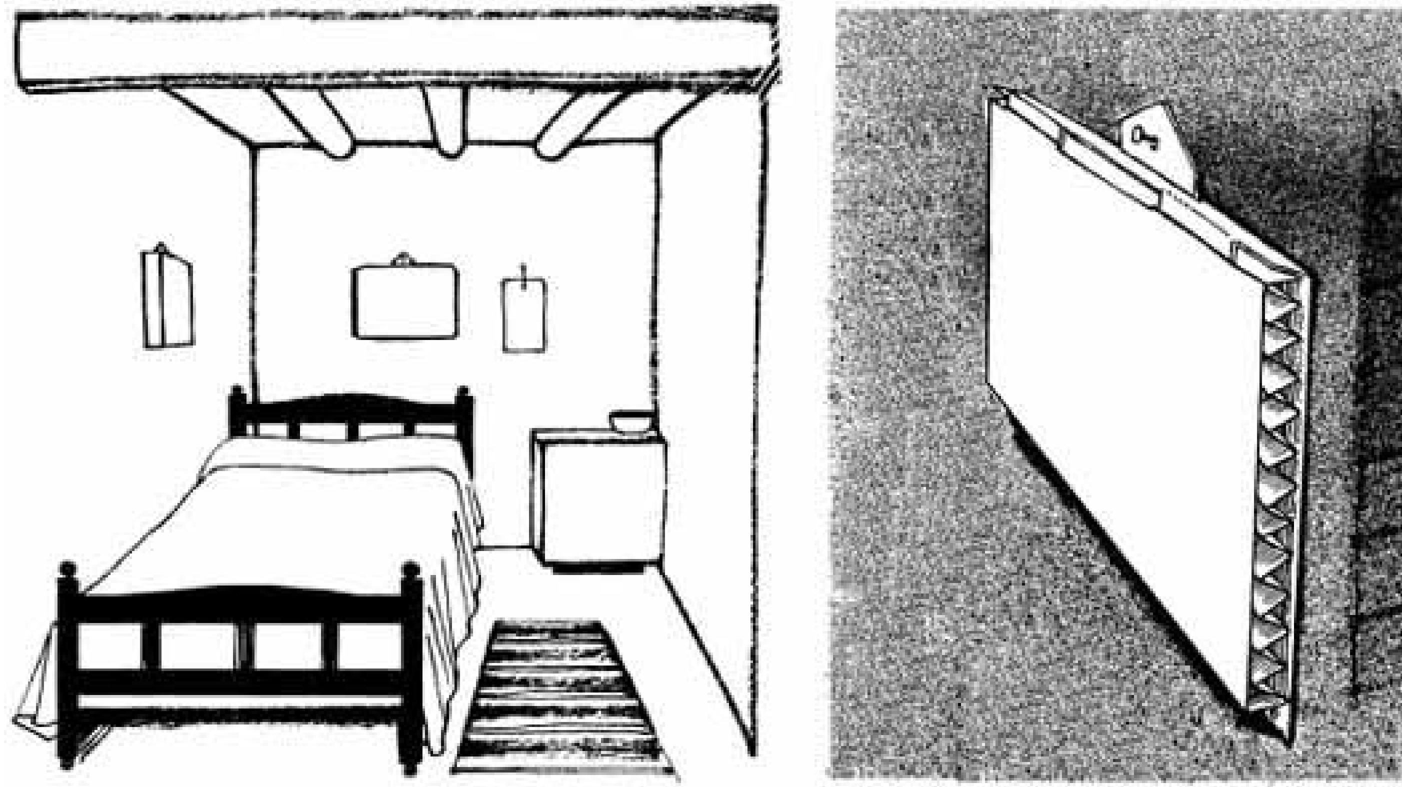


Fig. 3.31. The surveillance boxes are hung against walls close to beds and out of reach of children.

Surveillance sheets

A simpler method involves tacking sheets of coloured paper to the walls of the house in order to pick up recent deposits of bug faeces. If the papers are marked with the date they are put up, it is possible to tell during which period the bugs were present. Faecal streaks on a recently attached paper provide reliable evidence of current infestation. The best places to attach the papers are on walls close to beds. The sheets are considered to be as sensitive as surveillance boxes (*20*, *22*).

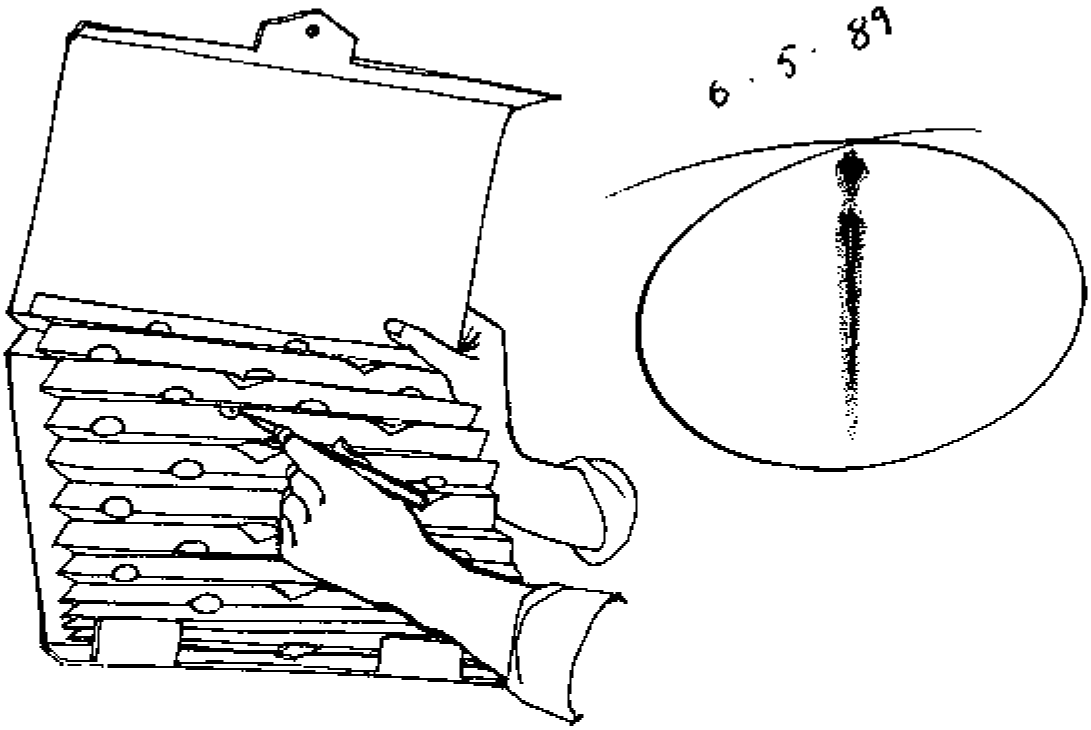


Fig. 3.32. Draw a circle around any faecal streak and note the date. As shown on the right, faecal streaks on vertical surfaces are distinctive.

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Chapter 4 - Bedbugs, fleas, lice, ticks and mites

Ectoparasites that live on the body, in clothing and in beds

There are many different species of bloodsucking fleas, lice, ticks and mites. Lice live on humans or in their clothing, while fleas are frequently found taking blood-meals on people and domestic animals. Bedbugs, which can be found in beds or furniture, feed on humans to obtain blood-meals. Some mites live in people's skin, e.g. the mites that cause scabies. Other mite species and ticks may take blood-meals on humans. Fleas, bedbugs and lice are insects, whereas ticks and mites belong to another group of arthropods, the Acarina. Unlike adult insects they have only two main sections to their body, and the adults have four pairs of legs (as opposed to three pairs in insects).

Bedbugs, head lice and crab lice do not carry disease, but their biting can be a serious nuisance. However, important diseases of humans and animals are transmitted by other arthropods dealt with here, among them the following:

- epidemic typhus and epidemic relapsing fever (body lice);
- plague and murine typhus (certain fleas);
- Lyme disease, relapsing fever and many viral diseases (ticks);
- scrub typhus (biting mites).

Bedbugs

Two species of bedbug feed on humans: the common bedbug (*Cimex lectularius*), which occurs in most parts of the world, and the tropical bedbug (*Cimex hemipterus*), which occurs mainly in tropical countries. They are a severe nuisance when they occur in large densities, being commonest in places with poor housing conditions. They are not important in the transmission of diseases, although they possibly play a role as vectors of hepatitis B virus.

Biology

Bedbugs have a flat, oval-shaped body with no wings, and are 4-7 mm long. Their colour is shiny reddish-brown but after a blood-meal they become swollen and dark brown in colour. There are three stages in the bedbug's life cycle: egg, nymph and adult (Fig. 4.1). The eggs are white and about 1 mm long. The nymphs look like adults but are smaller. Complete development from egg to adult takes from six weeks to several months, depending on temperature and the availability of food. Both male and female bedbugs feed on the blood of sleeping persons at night. In the absence of humans they feed on mice, rats, chickens and other animals. Feeding takes about 10-15 minutes for adults, less for nymphs, and is repeated about every three days. By day they hide in dark, dry places in beds, mattresses, cracks in walls and floors, and furniture; they are also found behind pictures and wallpaper; hiding places are also used for breeding. The bugs are frequently abundant in bedrooms in warm climates. Heated bedrooms in cooler climates are also favourable for the bugs, which cannot develop below 13°C (Fig. 4.2). Adults can survive for several years without food.

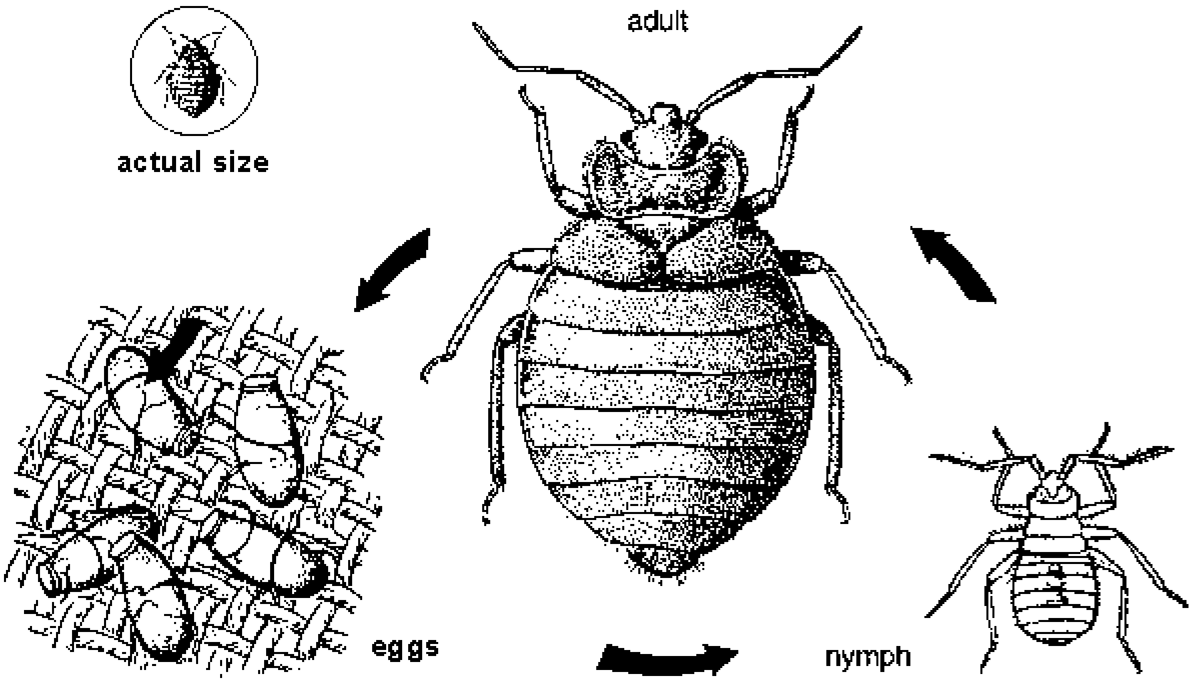


Fig. 4.1. Life cycle of the bedbug (by courtesy of the Natural History Museum, London).

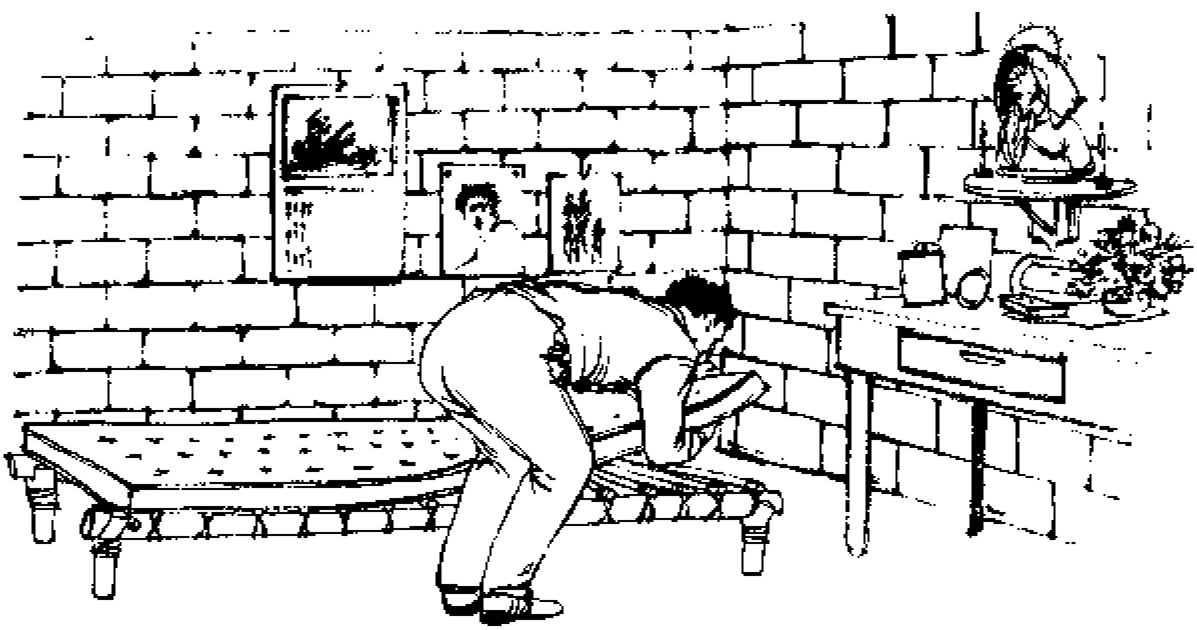


Fig. 4.2. Bedbugs are almost always found in bedrooms.

Dispersal

Because they have no wings, bedbugs travel only short distances. In poorly built houses with many suitable hiding places they crawl from one bedroom to another; they spread from one house to another mainly in second-hand furniture, bedding and, sometimes, clothes.

Public health importance

Bedbugs are not considered vectors of disease. It has been suggested that they play a role as vectors of the hepatitis B virus (*1*, *2*) but this was denied in a recent study in the Gambia (*3*). They are mainly important as a biting nuisance. Some people, especially those exposed for a long time, show little or no reaction to the bites, which appear as small red spots that may not even itch. People never bitten before may suffer from local inflammation, intense itching and sleepless nights. The bite produces a hard whitish swelling that often continues to bleed. Scratching may cause secondary infections.

In heavily infested houses where people may receive one hundred or more bites a night it is possible that the blood loss causes mild anaemia in infants.

Control measures

Bedbugs can move rapidly when disturbed and are not easily detected while biting. Some people may not even be aware that they are bitten each night by large numbers of bedbugs. Control measures are therefore carried out only if there is evidence of the presence of the insects.

Detection

Infestations can be detected by the examination of possible hiding places for the presence of live bugs, cast-off nymphal skins, eggs and excreta. The excreta may also be visible as small dark brown or black marks on bed sheets, walls and wallpaper (*4*). Houses with large numbers of bedbugs may have a characteristic unpleasant smell. Live bugs can be detected by spraying an aerosol of pyrethrum into cracks and crevices, thus irritating them and driving them out of their hiding places.

Repellents

Deet and other insect repellents are effective against bedbugs. They can be used by travellers who have to sleep in houses infested with the insects. However, repellents applied to the skin are unlikely to last the whole night. It is likely that burning mosquito coils offer some protection (see Chapter 1).

Simple household measures

Small numbers of bedbugs can occur in any household, especially when secondhand furniture or bedding is used. Light infestations can be treated by thoroughly cleaning infested articles, pouring boiling water over them and exposing them to sunlight. Aerosol spray cans can be used to spray household insecticides on to mattresses, in crevices in walls, and in other possible hiding places. Among the effective insecticides are the pyrethroids, propoxur, bendiocarb and dichlorvos. The procedure should be repeated if bugs are still found after a few weeks.

Total release fogger

This device is similar to the aerosol spray can but is designed to release the total contents of the can in a single shot through a special valve. The fog contains rather large droplets that do not penetrate well into crevices. Cans containing an insecticide-kerosene mixture should not be used for fogging because of the risk of explosion.

Impregnated mosquito nets

Mosquito nets impregnated with a long-lasting pyrethroid insecticide are effective in repelling and killing bedbugs (Fig. 4.3) (*5*, *6*). Such nets are increasingly popular for the control of malaria mosquitos. A commonly reported incidental benefit of the use of these nets is the complete disappearance of bedbug and head louse infestations, which makes the nets highly popular among people in bedbug-infested areas.

Smoke generators

Smoke generators, which are commercially available and usually contain pyre-throid insecticides, can be used to fumigate the interior of houses. They burn for 3-15 minutes and can be used only once. A smoke of very small droplets of insecticide is produced which can penetrate into cracks and crevices to kill bedbugs, fleas, flies, mosquitos and tropical rat mites. Smoke generators do not always work well, as the insecticide may settle on horizontal surfaces without penetrating into deep crevices. They have a brief effect and do not prevent reinvasion from neighbouring, untreated dwellings. They are mainly used where quick action is needed. A fumigant canister developed in South America against the triatomine bugs is described in Chapter 3, together with general instructions on how to abundant in bedrooms in warm climates. Heated bedrooms in cooler climates are also favourable for the bugs, which cannot develop below 13°C (Fig. 4.2). Adults can survive for several years without food.

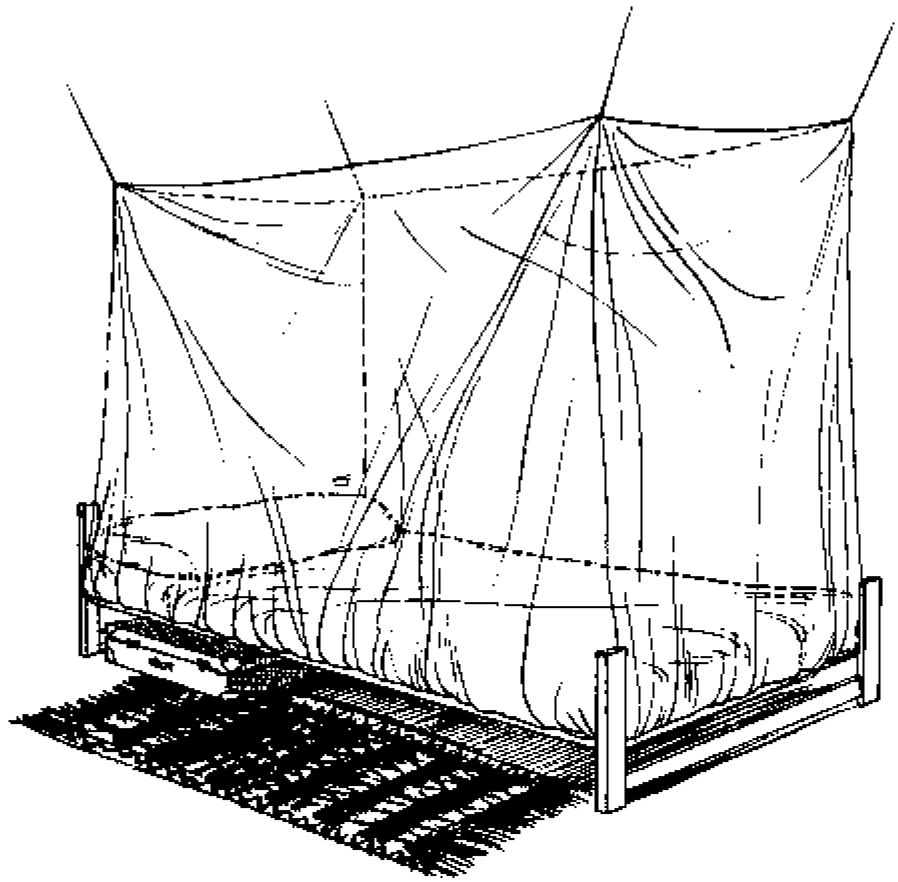


Fig. 4.3. The use of mosquito nets impregnated with a pyrethroid insecticide may result in the reduction or even eradication of bedbug and head louse infestations.

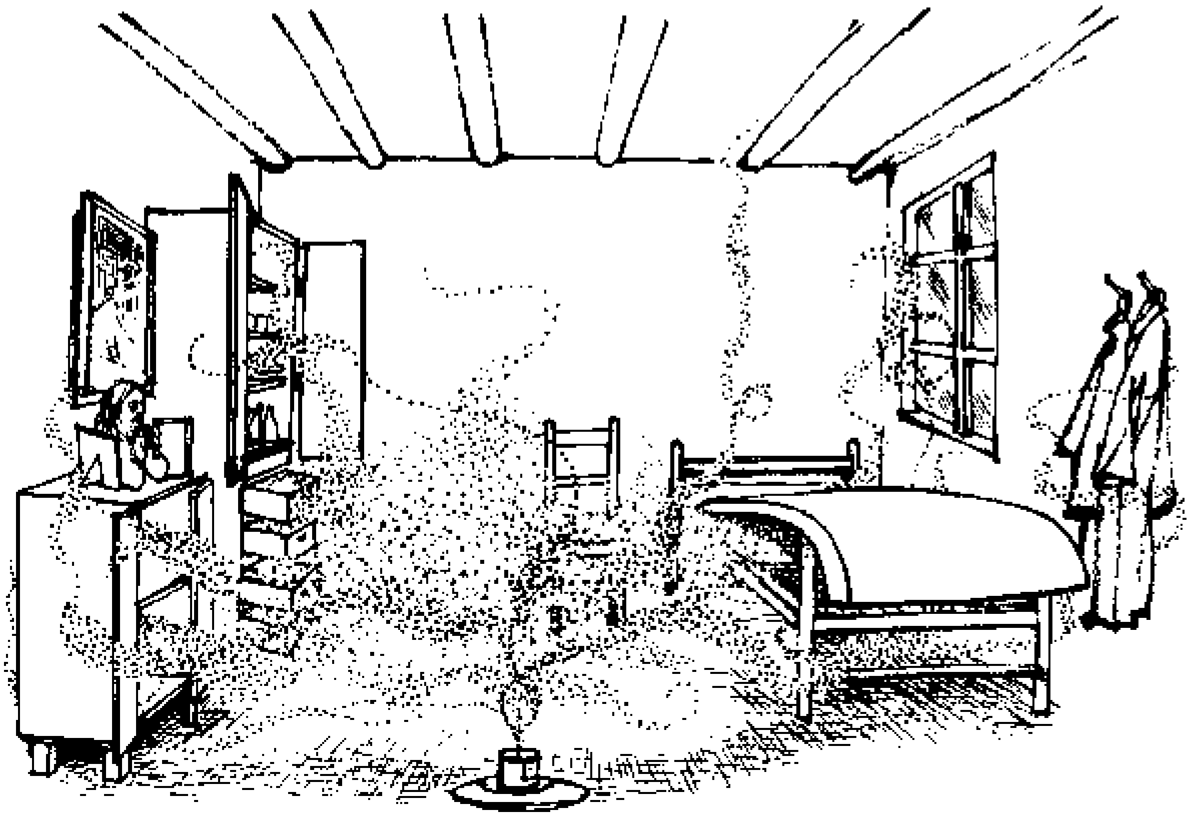


Fig. 4.4. The fumigant canister releases insecticide vapour for up to 15 minutes. x

Residual insecticides

Houses with heavy infestations need to be treated with long-lasting residual insecticide. One treatment is normally sufficient to eliminate bedbugs but, if an infestation persists, re-treatments should be carried out at intervals of not less than two weeks. In many countries, resistance of bedbugs to DDT, lindane and dieldrin is common. The insecticide selected should thus be one known to be effective against the target population (see Table 4.1). The addition of an irritant insecticide, e.g. 0.1-0.2% pyrethrin, helps to drive the bugs out of their hiding places, thus increasing exposure to the residual insecticide. Most pyrethroids are effective flushing and killing agents.

A residual spray is applied with a hand-operated compression sprayer (see Chapter 9). Special attention should be given to mattresses, furniture, and cracks and crevices in walls and floors (Fig. 4.5). In severe infestations, walls and floors should be sprayed until they are visibly wet (point of run-off). Usually this corresponds to 1 litre per 50 m^2 on non-absorbent surfaces and to 5 litres or more per 50 m^2 on absorbent surfaces such as those of mud-brick walls. Rooms in humid tropical countries must be treated in the morning so that they are dry and suitable for re-entry in the evening. Mattresses and bedding should be treated carefully to avoid staining and soaking, and should be thoroughly aired and dried before use. Hand dusters containing insecticide powder may be used to dust mattresses and bedding, to avoid wetting them. Bedding used for infants should not be treated with residual insecticide, but with a short-lasting insecticide such as may be found in most aerosol spray cans.

Table 4.1 Residual insecticides for use against bedbugs

Insecticide	Concentration in spray (%)
malathion	2.0
fenitrothion	0.5-1.0
propoxur	2.0
carbaryl	1.0
diazinon	0.5
bendiocarb	0.2-0.3
fenchlorvos	1.0
pirimiphos methyl	1.0
propetamphos	0.5-1.0
permethrin	0.5
cyfluthrin	0.01
deltamethrin	0.005
lambdacyhalothrin	0.005

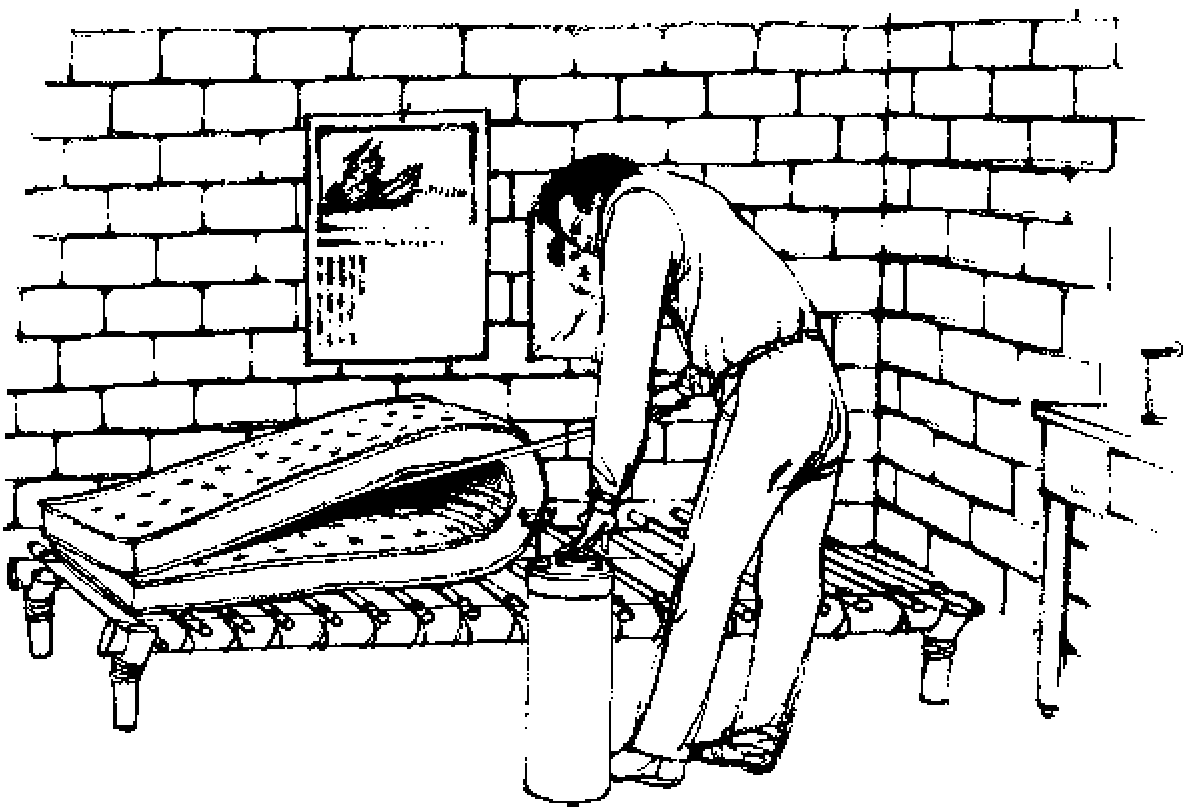


Fig. 4.5. Spray residual insecticide on to mattresses, cracks in walls, floors and other hiding places with a compression sprayer.

Bedbugs and malaria control

House spraying against malaria was very popular in many tropical countries, partly because it killed bedbugs. Unfortunately, the bugs quickly developed resistance to the insecticides, resulting in numerous complaints that spraying no longer controlled bedbugs, even though it still killed mosquitos.

Another possible explanation for the increase in the numbers of bedbugs observed is that the insecticide spray irritated the bugs, causing them to leave their hiding places. Seeing many more bedbugs than before, people believed that spraying caused an increase in the bug population (*7*, *8*).

As a result, many householders refused malaria spraying teams access to their homes. It is possible that in some areas the occurrence of bedbugs contributed indirectly to the ineffectiveness of malaria control programmes.

Fleas

Fleas are small, wingless bloodsucking insects (order Siphonaptera) with a characteristic jumping movement. They feed mainly on mammals but also on birds. Of the 3000 species only a dozen commonly attack humans. The most important species are the rat flea, the human flea and the cat flea (Fig. 4.6). Their bites can cause irritation, serious discomfort and loss of blood. The rat flea is important as a vector of bubonic plague and flea-borne typhus. Cat fleas incidentally transmit tapeworms. The sand flea or jigger burrows into the skin of humans and may cause infections. Fleas that bite people occur in most parts of the world.

Biology

The life cycle of fleas has four stages: egg, larva, pupa and adult (Fig. 4.7). Adult fleas are 1-4 mm long and have a flat narrow body. They are wingless with well developed legs adapted for jumping. They vary in colour from light to dark brown. The larvae are 4-10 mm long and white; they have no legs but are very mobile. The cocoon (pupal stage) is well camouflaged because it is sticky and soon becomes covered with dust, sand and other fine particles.

Both female and male fleas take blood-meals. Fleas breed close to the resting and sleeping places of the host, in dust, dirt, rubbish, cracks in floors or walls, carpets, animal burrows and birds' nests. High humidity is required for development. The larvae feed on organic matter such as the faeces of the host, small dead insects and undigested blood expelled by adult fleas. At the end of the larval period the larva spins a loose whitish cocoon within which it develops into a pupa.

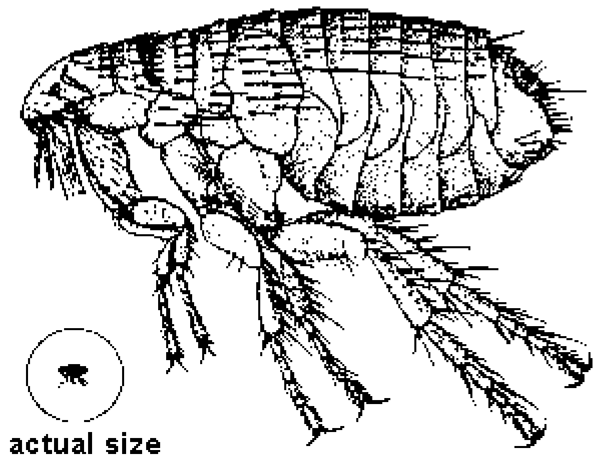


Fig. 4.6. A cat flea (*Ctenocephalides felis felis*) (by courtesy of the Natural History Museum, London).

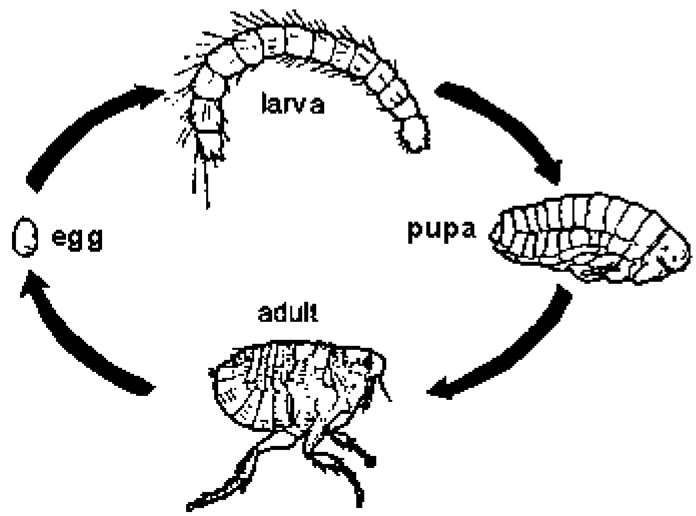


Fig. 4.7. The life cycle of the flea (by courtesy of the Natural Natural History Museum, London).

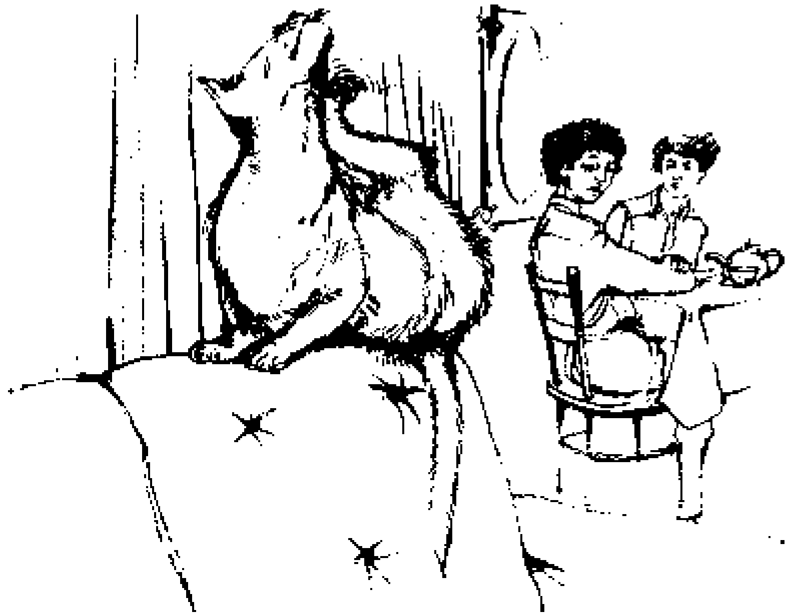


Fig. 4.8. A scratching cat is an indication of a flea infestation.

The adult fleas are fully developed within 1-2 weeks but only emerge from the cocoons after receiving a stimulus, such as the vibrations caused by movement of the host. In vacant houses they may survive in the cocoons for up to a year. People moving into a vacant house can cause many fleas to emerge simultaneously from the cocoons and attack people or animals in large numbers. Under optimal conditions the development from egg to adult takes 2-3 weeks.

Behaviour

Fleas avoid light and are mostly found among the hairs (Fig. 4.8) or feathers of animals or in beds and in people's clothing. If possible, a flea will feed several times during the day or night. Heavy infestations with fleas are recognized by marks on clothing and bedding of undigested blood ejected by the fleas. Most flea species feed on one or two host species, but in the absence of their normal host they feed on humans or other animals. Adult fleas can survive several months without food. Fleas move around by jumping; some species can jump as high as 30 cm.

Public health importance

Nuisance

Humans are most commonly bitten by the cat flea, *Ctenocephalides felis* and, less commonly, the dog flea, *C. canis*. The so-called human flea (*Pulex irritans*) is, in spite of its name, less important. Fleas jump up from the ground and most frequently attack people on the ankles and legs, the easiest parts to reach, although sleeping people can be attacked anywhere on the body. Flea bites cause irritation and sometimes extreme discomfort. Heavy infestations may cause allergic reactions and dermatitis.

Plague

Plague is a disease caused by the bacterium *Yersinia pestis*. It occurs primarily in wild animals, such as rats and other rodents. Plague bacteria are transmitted by fleas, and humans may be infected by fleas that have fed on infected animals. In the past, plague was called the black death and caused disastrous epidemics.

Plague is still dangerous because it occurs widely in rodent populations. Rural or sylvatic plague may be contracted in the western USA, South America, Africa, the former USSR, parts of the eastern Mediterranean area, and central and southeast Asia. Human plague frequently occurs in several countries in Africa, Bolivia/north-eastern Brazil, Ecuador, Myanmar, Peru and Viet Nam (*9*).

Rural plague is acquired by people entering rural areas and handling wild animals. Most at risk are hunters who may be bitten by infected fleas while handling recently killed animals.

Urban plague may occur when rats living in and around human dwellings are infected. Rat fleas (*Xenopsylla* species) that normally feed on rats may occasionally feed on humans and thus spread the disease to them. When rodents infected with plague die the fleas leave their hosts and are then likely to attack and infect people. Other fleas, such as the human flea, may subsequently transmit the disease from person to person.

There are three clinical types of plague:

• *Bubonic plague*. Swellings (buboes) filled with bacteria develop in the lymph nodes, especially in the armpits and groin. This form is normally transmitted to humans by infected fleas. If left untreated, it causes death in about 50% of cases.

• *Pneumonic plague*. This is a secondary form in which the lungs become affected. It is highly contagious, the plague bacillus easily spreading from person to person in sputum or droplets coughed up or sneezed by sick people. Pneumonic plague occurred in epidemics in past centuries, killing millions of people. If left untreated it very often results in death.

• *Septicaemic plague*. The bloodstream is invaded by the plague bacillus, resulting in death before one of the above two forms can develop.

Prevention and control

Partial immunity is acquired after an infection. A vaccine is available which provides protection for a period of only a few months. Treatment with streptomycin, tetracycline or its derivatives or chloramphenicol is highly effective if used within a day after the onset of symptoms.

Urban plague is controlled by rapidly applying insecticide dusts in rodent burrows and on to rodent runways where it will be taken up by the animals on their fur, thus killing the vector fleas. Dusting against fleas should be followed by measures to control rodents.

People working in the field may protect themselves by dusting their clothing with insecticidal powder, using impregnated clothing, and using repellents on a daily basis.

Flea-borne typhus

Flea-borne typhus, also called murine typhus fever, is caused by *Rickettsia typhi* and occurs sporadically in populations of rats and mice. It is transmitted mainly by rat fleas and cat fleas, and humans can become infected as a result of contamination from the dried faeces and crushed bodies of the fleas. The disease occurs worldwide and is found in areas where people and rats live in the same building. Its symptoms are similar to those of louse-borne typhus (see p. 257) but milder.

Prevention and control

Immunity is acquired after the first infection. The treatment of sick people is similar to that for louse-borne typhus (see p. 257). Control is carried out by applying residual insecticides to the runs, burrows and hiding places of rats. If these measures are successful in killing fleas, rodent control measures can be taken (see p. 250, box).

Other diseases

Fleas occasionally transmit other diseases and parasites from animals to humans, for instance tularaemia caused by the bacillus *Francisella tularensis*, and the parasitic tapeworms that occur in dogs and cats. Children playing with domestic pets may become infected by swallowing fleas that carry the infective stage of the worms.

Control measures

The recommended control methods depend on whether the intention is to deal with fleas as a biting nuisance or as vectors of disease.

Fleas as a nuisance

Individual self-protection

An effective repellent, such as deet, applied to skin and clothing, prevents fleas from attacking. A disadvantage is that repellents applied to the skin last only a few hours (see Chapter 1). Longer-lasting protection is obtained by dusting clothing with insecticide powder (see p. 262) or by using insecticide-impregnated clothing (see Chapter 1).

Simple hygienic measures

Fleas and their eggs, larvae and cocoons can be effectively removed by keeping houses well swept and floors washed. Removal with a vacuum cleaner is also effective. When people enter an infested house that has been vacant for some time, large numbers of newly emerged fleas may attack. The treatment of floors with detergents, insecticides or a solution of naphthalene in benzene is recommended; care should be taken to avoid inhaling benzene fumes.

Application of insecticides

Heavy infestations can be controlled by spraying or dusting insecticides into cracks and crevices, corners of rooms and areas where fleas and their larvae are likely to occur.

Insecticides can also be applied to clothing and the fur of animals. Fumigant canisters that produce aerosols of quick-acting insecticides (e.g. the pyre-throids, propoxur and bendiocarb) kill fleas directly and are convenient to use (see p. 240 and Chapter 3). However, the insecticidal effect is brief and reinfestations may appear quickly.

Cat and dog fleas

Fleas can be detected in the hair around the neck or on the belly of cats and dogs. Treatment involves applying insecticidal dusts, sprays, dips or shampoos to the fur. Dusts are safer to use than sprays because the insecticides are less likely to be absorbed through the skin in the dry form. Dusts also produce less odour and do not affect the skin as much as sprays. Carbaryl and malathion should not be used on kittens and puppies under four weeks of age. Pets can be provided with plastic flea collars impregnated with an insecticide. Flea collars are effective for 3-5 months, whereas other treatments give only short-term control.

Recently, lufenuron tablets have been used to control fleas in cats and dogs. The tablets are administered once monthly at a dose of 30 mg per kg of body weight to cats and 10 mg per kg of body weight to dogs and are safe for use in pregnant and nursing animals. Lufenuron is taken up by the female flea during feeding and acts by inhibiting egg development (*10*).

Dusts must be rubbed thoroughly into the hair and can be applied by means of a shaker (Fig. 4.9). They must not be allowed to get into the eyes, nostrils and mouths of animals. Heavy applications should not be made to the abdomen as the material will be licked off. Application should begin above the eyes and all the areas backward to the tail and haunches should be covered, ensuring thorough treatment around the ears and underneath the forelegs. A small animal can be treated with one tablespoonful of dust, while 30g may be required for a large dog. Sprays must wet the hair completely and can be applied with a hand-compression sprayer. It is also possible to spray with an insecticide aerosol from a pressurized spray can.

Fig. 4.9. Dusting a dog with insecticide powder to control fleas.

Re-treatment may be necessary if reinfestation occurs. Important sources of reinfestation are the places where animals or humans sleep or spend much time, such as beds, bedding and kennels. Where possible, animal bedding should be burned or laundered in hot soapy water. A vacuum cleaner may be used to remove accumulations of dust that contain flea larvae and pupae, and infested premises can then be treated with a residual insecticide. Treatment with insecticidal powders or solutions is possible (*11*). Because flea cocoons are much less susceptible to insecticides than the larvae and adults, treatments should be repeated every two weeks over a period of six weeks to ensure that all emerging fleas are killed (*12*).

Human flea

This flea species does not usually remain on the person after feeding and by day it rests in cracks, crevices, carpets and bedding. Regular cleaning of houses, and of bedrooms in particular, should prevent large infestations.

More effective control is achieved by dusting or spraying insecticides on to mattresses and cracks and crevices in floors and beds. Bedding left untreated should be washed and cleaned during insecticide application. Fleas in many parts of the world have developed resistance to DDT, lindane and dieldrin (*13*-*15*). Suitable insecticides for spraying or dusting are indicated in Table 4.2.

Table 4.2 Insecticides and application methods effective against fleas

Type of	Pesticide and formulation

application	
Residual spray	malathion (2%), diazinon (0.5%), propoxur (1.0%), dichlorvos (0.5-1.0%), fenchlorvos (2%), bendiocarb(0.24%), natural pyrethrins (0.2%), permethrin (0.125%), deltamethrin (0.025%), cyfluthrin (0.04%), pirimiphos methyl(1%)
Pesticide power (dust)	malathion (2-5%), carbaryl (2-5%), propoxur (1%), bendiocarb (1%), permethrin (0.5-1.0%), cyfluthrin (0.1%), deltamethrin (0.05%), temephos (2%), pirimiphos methyl(2%), diazinon (2%), fenthion (2%), fenitrothion (2%), jodfenphos (5%), (+)-phenothrin (0.3-0.4%)
Shampoo	propoxur (0.1%), (+)-phenothrin (0.4%)
Fumigant canister	propoxur, dichlorvos, cyfluthrin, permethrin, deltamethrin, (+)-phenothrin
Flea collar for dog or cat	dichlorvos (20%), propoxur (10%), propetamphos, diazinon
Repellent	diethyl-toluamide (deet), dimethyl phthalate, benzyl benzoate

Retreatment is probably not needed if all infested places in a house are treated or cleaned. Infants' bedding should not be treated but should be thoroughly washed.

Fleas that transmit diseases

Control measures during epidemics of plague or typhus must be effected in two stages:

(1) insecticidal dusting of rat habitats to kill rat fleas;
(2) rat control.

A control campaign with the sole aim of killing rodents could result in increased disease transmission to humans: the deaths of many rodents could cause large numbers of fleas to leave the dead hosts and seek alternative sources of blood.

Insecticidal powder

The most common and effective method of controlling rodent fleas has been to use DDT in a 10% dust formulation. Alternative insecticides in dust formulation are increasingly used (see Table 4.2) because of the resistance of fleas in many areas to DDT and also because of environmental concerns.

Dust is applied to burrows, runways and other sites where rodents are likely to pick it up. When the rodents groom themselves they spread the dust on their fur, thus killing the fleas.

Before control is begun, it is important to know where rodent burrows and runways are. To save insecticide, the burrows should first be closed off; only those that are subsequently reopened should be treated. Insecticidal dust should be blown into each burrow with a duster. A patch of dusting powder, 1 cm in depth, should be left around the opening. Patches of dust 15-30 cm wide should be placed along runways. Dust should be applied only where it will remain undisturbed by humans and the wind. Care must be taken not to apply insecticides to areas where they can contaminate food.

Many insecticidal dusts remain effective for 2-4 months if used indoors in undisturbed places.

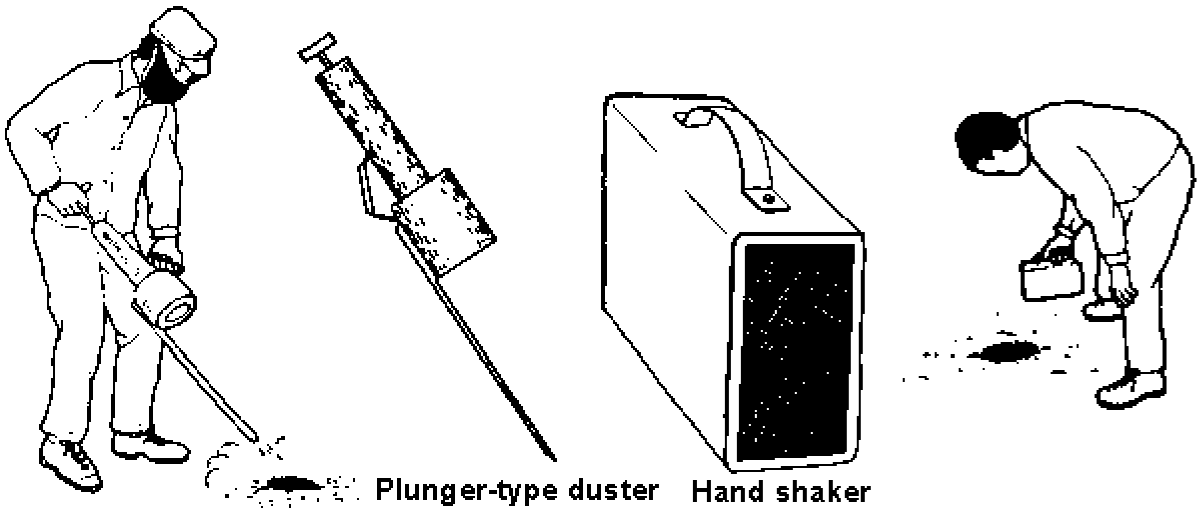


Fig. 4.10. Equipment for applying anti-flea dusts (© WHO).

A plunger-type duster is suitable for fast applications of dust to rodent burrows and runways, in attics and spaces under buildings. It consists of an air pump like a bicycle pump to which a container for the dust is attached. The air from the pump is led into this container, agitating the contents and expelling them from an orifice (Fig. 4.10).

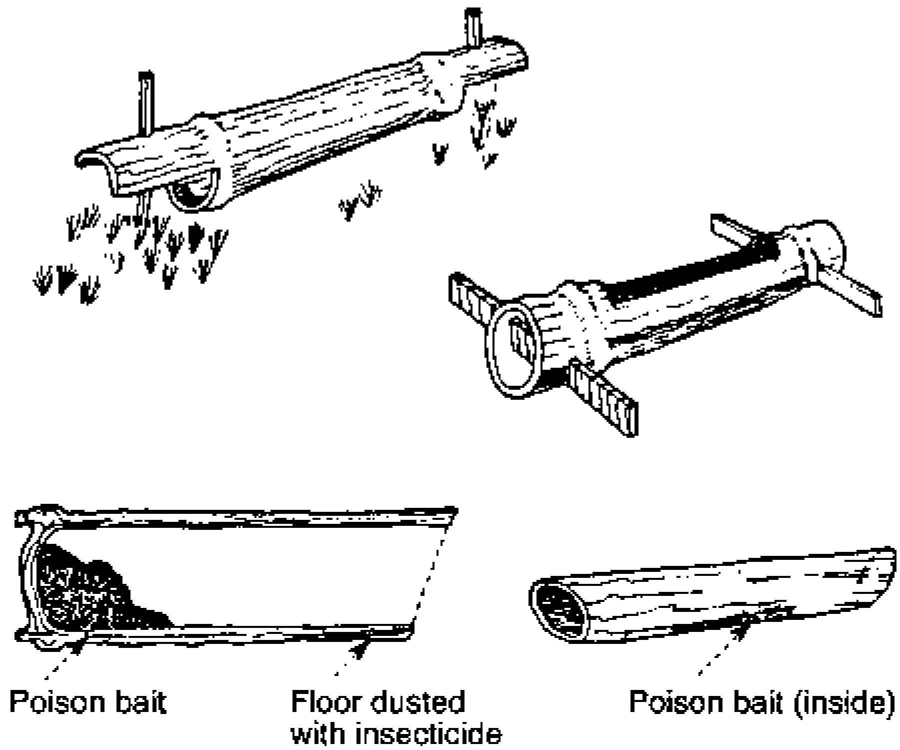
Alternatively, a hand shaker can easily be made from a can by fitting a 16-mesh screen at one end. A can with nail-holes punched in the top can also be used. Insecticidal dust of low toxicity can be applied to human clothing or the fur of animals with such equipment.

Integrated rat and flea control

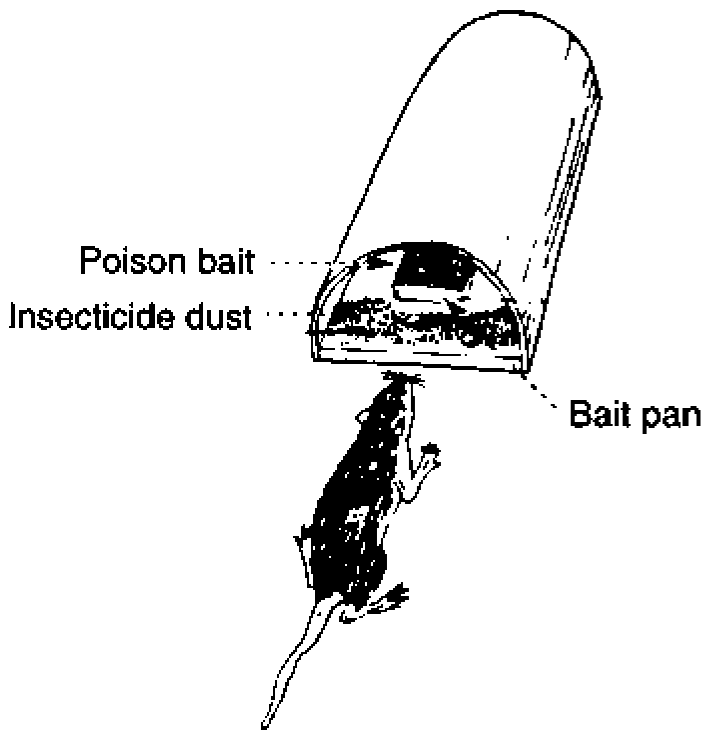
To control urban outbreaks of plague or typhus, insecticides to kill rat fleas are applied at the same time as or a few days earlier than rat poisons. Suitable rat poisons are warfarin, coumafuryl, difenacoum, brodifacoum, coumatetralyl, bromadialone, chlorophacinone and zinc phosphide (*16*, *17*).

In places where food for human consumption is stored and in crowded areas, such as markets, it is safer to use bait boxes (Fig. 4.11) in which the rodents contaminate themselves with the antiflea dust before they die from eating the toxic bait. Bait boxes can be placed along rodent runs at intervals of 60 metres. A suitable bait consists of 100g of rolled oats mixed with rat poison.

Fig. 4.11. Models of bait boxes.



(a) Boxes made of bamboo.



(b) A bait box made of floorboard (30 x 20 cm) covered by a metal roof (© WHO).

Sand fleas or jigger fleas

The sand flea, chigoe or jigger flea (*Tunga penetrans*) is not known to transmit disease to humans but, unique among the fleas, it is a nuisance because the females burrow into the skin. Sand fleas occur in the tropics and subtropics in Central and South America, the West Indies and Africa.

Biology

The larvae of sand fleas are free-living and develop in dusty or sandy soil. The adults are initially also free-living but, after copulation, the fertilized females attach themselves under the skin of humans, pigs, dogs, poultry and other animals, penetrating soft areas of skin, for instance cracks in the soles of the feet, between the toes, and under the toenails. Other parts of the body may also be affected.

Public health importance

Usually a person is infested by only one or two jiggers at a time but infestation with hundreds is possible. People who do not wear shoes, such as children, are most commonly affected. The flea burrows entirely into the skin with the exception of the tip of the abdomen. It feeds on body fluids and swells up to the size and shape of a small pea in 8-12 days (Fig. 4.12). The body of the female flea is completely filled with thousands of eggs which are expelled in the next weeks (Fig. 4.13). Most of the eggs fall to the ground where they hatch after a few days.

Fig. 4.12. The female sand flea attacks bare-footed persons by burrowing into soft skin on the feet (*18*).

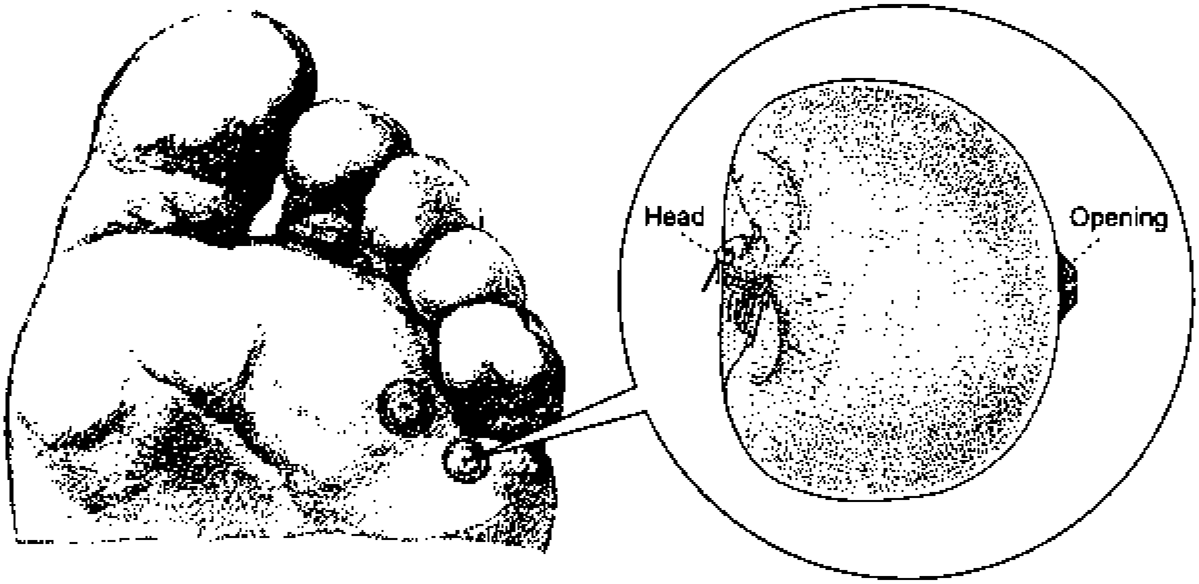


Fig. 4.13. Detail of foot with jigger infections. Eggs are expelled through the dark opening in the centre (by courtesy of the Natural History Museum, London).

Symptoms

An infestation begins to irritate and itch when the female is almost fully developed. Sometimes it causes severe inflammation and ulceration. If the female flea dies in the skin it may cause a secondary infection which, if ignored, could lead to tetanus, gangrene and even the loss of a toe.

Natural extrusion of the egg sac or removal of the jigger with a dirty pin or needle leaves a tiny pit in the skin which may develop into a sore. The sore may extend and develop into a septic ulcer. An infection under a toenail may cause pus to form.

Prevention, control and treatment

Jigger populations often maintain themselves in the domestic environment by breeding on livestock and domestic animals. Efforts should be made to remove the jiggers from these animals. Infections in dogs can be controlled by the administration of ivermectin (0.2 mg/kg of body weight) or by bathing the feet with dichlorvos (0.2%) (*19*). The former treatment may kill other parasites, such as *Dermatobia* larvae, which causè skin infections. In infested areas, people should inspect their feet daily for freshly burrowing jiggers, which are visible as minute black spots and cause an itchy sensation.

Wearing shoes prevents attacks. The fleas may also be deterred by a repellent applied to the skin, although walking bare-footed in dirt quickly removes it. If it is possible to locate the area of soil where the jiggers originate it could be burnt off or sprayed with a suitable insecticide in an effort to kill the fleas.

Treatment

With some skill it is possible to remove the jigger with forceps or with a sharp object, such as a needle, a thorn or the tip of a knife (Fig. 4.14). The object and the site of infection should be cleaned, if possible with alcohol, to reduce the risk of infection. Removal can be done in a painless way but care should be taken not to rupture the egg sac. Infection may result if eggs or parts of the flea's body are left in the wound. After removal, the wound should be dressed antiseptically (with alcohol or iodine) and protected until healed.

Lice

Lice are small bloodsucking insects that live on the skin of mammals and birds. Three species of lice have adapted themselves to humans: the head louse (*Pediculus humanus capitis*), the body louse (*Pediculus humanus*) and the crab or pubic louse (*Pthirus pubis*) (Fig. 4.15). All three species occur worldwide. Lice infestations can cause severe irritation and itching. In addition the body louse can transmit typhus fever, relapsing fever and trench fever. Outbreaks of louse-borne typhus fever, sometimes claiming thousands of lives, have occurred in colder areas where people live in poor, crowded conditions, especially in some highland areas of Africa, Asia and Latin America.

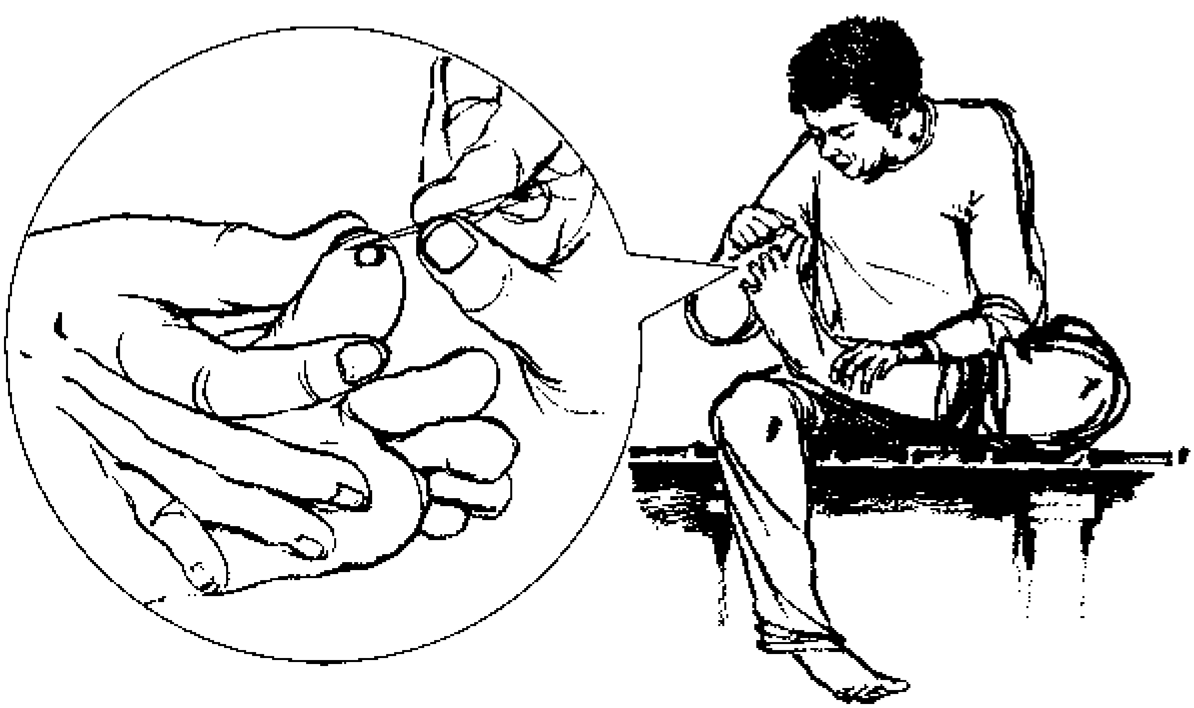


Fig. 4.14. The egg sac of the sand flea can be removed with a sharp object.

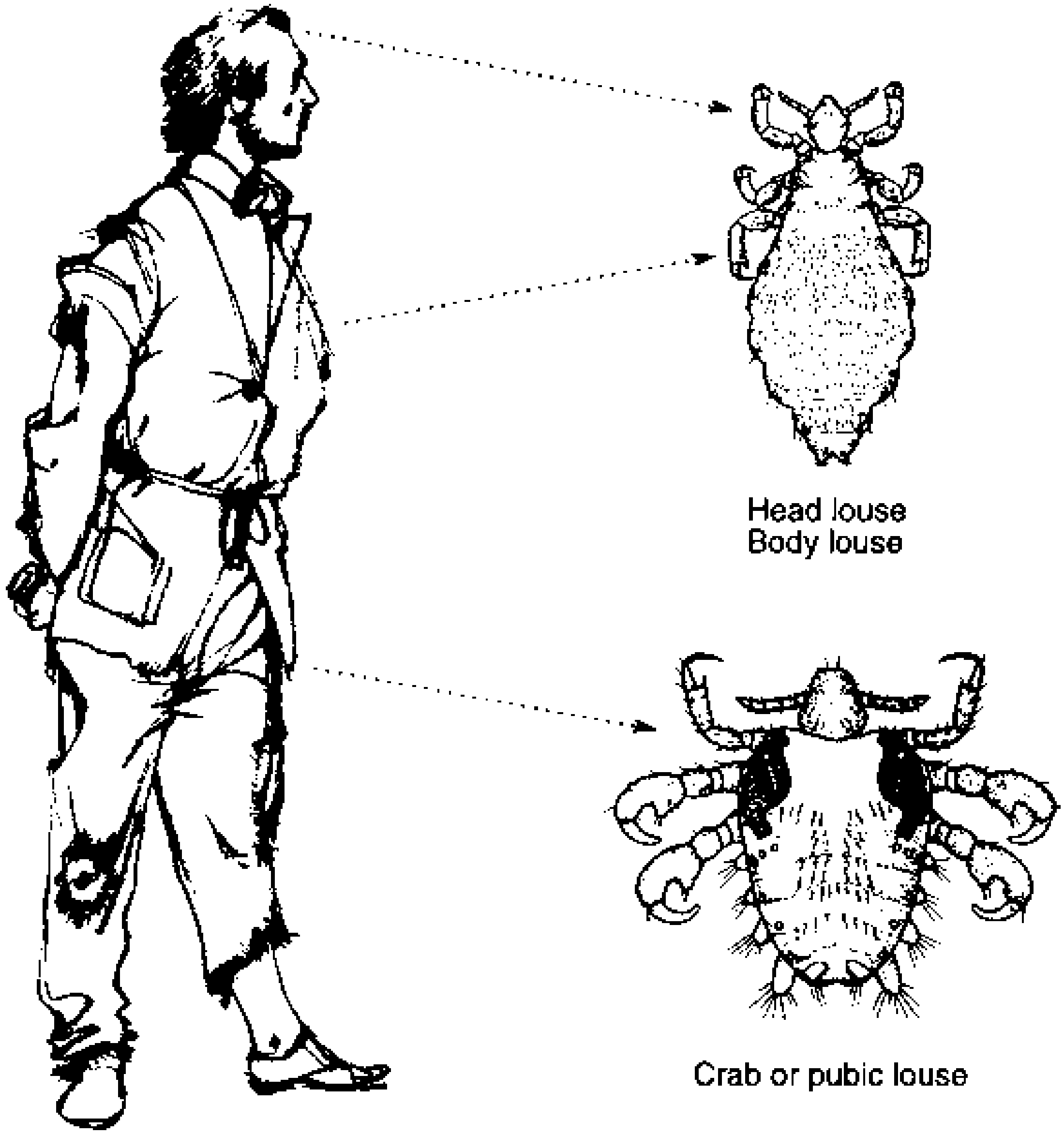


Fig. 4.15. Human sucking lice are flat wingless insects with legs adapted for grasping hairs (infested man © L. Robertson; Lice © WHO).

Biology

The three species live only on humans (not normally on animals) and feed on human blood; the life cycle has three stages: egg, nymph and adult (Fig. 4.16). Development from egg to adult takes about two weeks. The white eggs (called nits) are glued to a hair or, in the case of the body louse, to fine threads on clothes. The nymphs are similar to the adults but much smaller. Fully grown lice are up to 4.5 mm long and feed by sucking blood. Feeding occurs several times a day. Lice can only develop in a warm environment close to human skin, and die within a few days if they lose contact with the human body. They are normally spread by contact, e.g. in overcrowded sleeping quarters and other crowded living conditions.

The three species of human lice are found on different parts of the body:

- the head louse occurs on the scalp and is most common in children on the back of the head and behind the ears;

- the pubic louse or crab louse is mainly found on hair in the pubic region but it may spread to other hairy areas of the body and, rarely, the head;

- the body louse occurs in clothing where it makes direct contact with the body; it is similar to the head louse but slightly bigger.

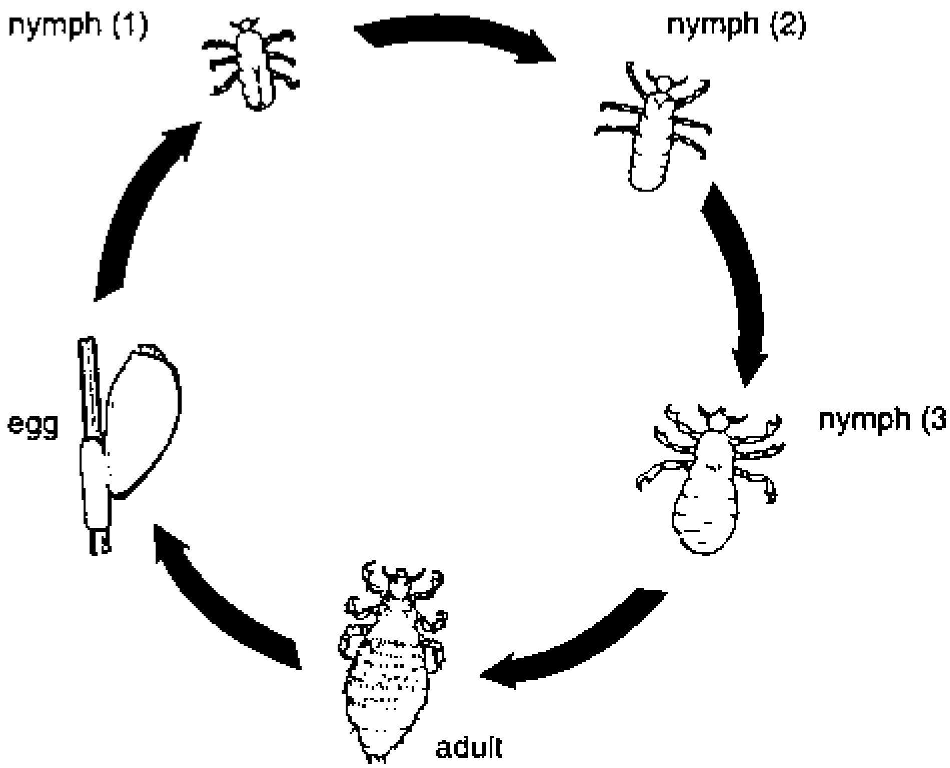


Fig. 4.16. Life cycle of the louse (© WHO).

Body lice

Body lice are most commonly found in clothing, especially where it is in direct contact with the body, as in underwear, the crotch or fork of trousers, armpits, waistline, collar and shoulders. They attach themselves to body hair only when feeding. The eggs are attached to thin threads of clothing. Body lice are most common in colder areas where people do not frequently wash or change clothes.

Body lice are spread by close contact between people. They are most commonly found, therefore, on people living in overcrowded, unhygienic conditions, as in poorly maintained jails, refugee camps and in trenches during war. They also spread by direct contact between people in crowded transport vehicles and markets. Body louse infestations may also be acquired through sharing bedding, towels and clothing or by sitting on infested seats, chair covers or cushions.

Head lice

The head louse is the most common louse species in humans. It lives only in the hair on the head and is most often found on children. The eggs (or nits) are firmly glued to the base of hairs of the head, especially on the back of the head and behind the ears (Figs. 4.17 and 4.18). Because the hairs grow about a centimetre a month it is possible to estimate the duration of an infestation by taking the distance between the scalp and the furthest egg on a hair. Infested persons usually harbour 10-20 adult head lice. The females lay 6-8 eggs per day. Head lice are spread by close contact between people, such as children at play or sleeping in the same bed. Head lice are also spread by the use of other people's combs that carry hairs with eggs or lice attached.

Crab or pubic lice

Crab lice, also called pubic lice, are greyish-white and crab-like in appearance. They are most often found on hair in the pubic region, and eggs are laid at the base of the pubic hair. Heavy infestations may spread to other hairy areas of the body, such as the chest, thighs, armpits, eyelashes, eyebrows and beard. Crab lice are mainly spread through sexual or other close personal contact, and are most common in young, sexually active adults.

Fig. 4.17. Inspection of the hair for head lice. Girls tend to have heavier infestations than boys.

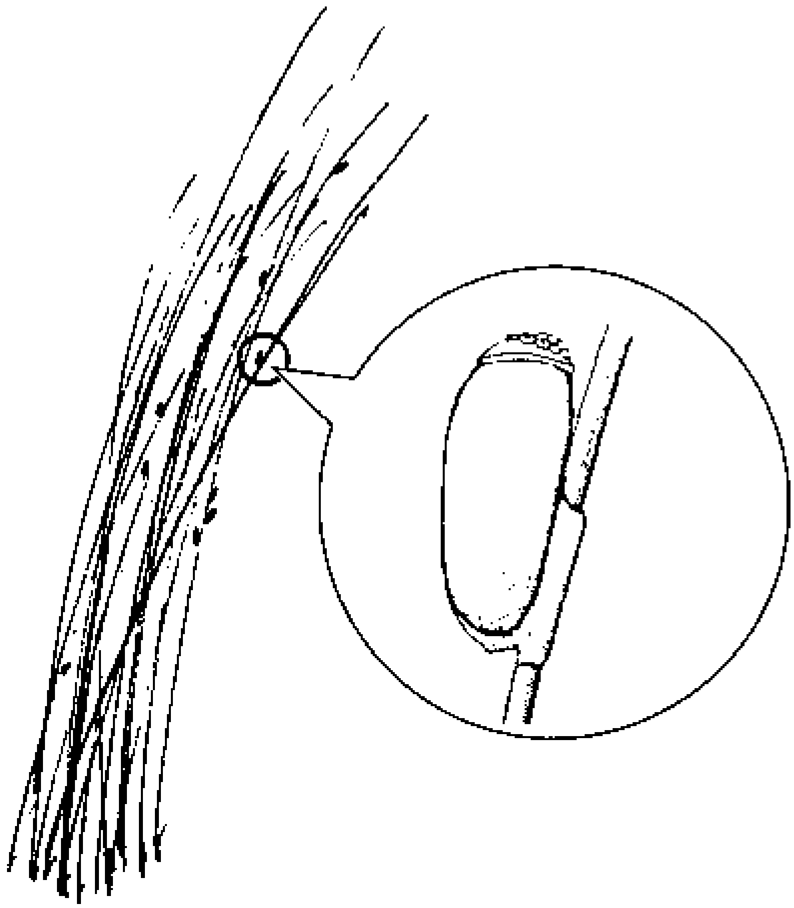


Fig. 4.18. Close-up of hair infested with lice and eggs (by courtesy of the Natural History Museum, London).

Public health importance

Only the body louse is a vector of human diseases. It transmits typhus fever, relapsing fever and trench fever.

Nuisance

Lice feed several times a day and heavy infestations can cause intense irritation and severe itching. Toxic reactions to the saliva injected into the skin may lead to weariness and a general feeling of illness.

Louse-borne typhus fever

This disease is caused by a microorganism, *Rickettsia prowazekii*, and is an acute, highly infectious disease with headache, chills, fever and general pains as symptoms. It may be fatal in 10-40% of untreated cases.

The disease has occurred on all continents except Australia. It is prevalent in cool areas where heavy clothing is worn and where the vector is most common. In the past the disease was most common during war and famine. Today, foci of transmission are found in mountainous regions of South America, in Central and East Africa and in the Himalayas.

Transmission

Body lice take the disease organisms up with the blood of an infected person and then expel it with their faeces. Since louse faeces dry to form a fine black powder they are easily blown about. The powder can infect small wounds, such as those caused by scratching, or the mucous membranes of the nose and mouth. Because the disease organism can remain alive for at least two months in dried louse faeces, it is dangerous to handle the clothing or bedding of patients with typhus.

Treatment

Effective treatment is possible with tetracycline, doxycycline or chloramphenicol.

Prevention and control

A vaccine has been prepared but is not yet commercially available. Infection can be prevented by controlling the body lice. Epidemic outbreaks are controlled by the application of a residual insecticide to the clothing of all persons in affected areas.

Louse-borne relapsing fever

This disease is caused by a microorganism, *Borrelia recurrentis*. Infected people suffer periods of fever lasting 2-9 days which alternate with periods of 2-4 days without fever. Usually, about 2-10% of untreated persons die but the mortality rate may be as high as 50% during epidemics. The disease occurs in limited areas of Africa, Asia and South America.

Transmission

Louse-borne relapsing fever occurs under similar conditions to those of typhus fever and the two diseases may appear together. Humans become infected by crushing infected body lice between the fingernails or the teeth. The disease organisms are thus released and can enter the body through abrasions, wounds or the mucous membranes of the mouth.

Treatment

Treatment is possible with tetracycline.

Prevention and control

Prevention and control are as described for typhus fever; no vaccine is available.

Trench fever

This bacterial disease, caused by *Rochalimaea quintana*, involves intermittent fever, aches and pains all over the body, and many relapses. Infection rarely results in death.

The disease can probably be found wherever the human body louse exists. Cases have been detected in Bolivia, Burundi, Ethiopia, Mexico, Poland, the former USSR and North Africa. Epidemics occurred during the First and Second World Wars among troops and prisoners living in crowded and dirty conditions, hence the name “trench fever”.

Transmission

Transmission occurs through contact with infected louse faeces, as for typhus fever.

Treatment

Tetracycline, chloramphenicol and doxycycline are probably effective but, as the disease is rather mild, they have not been adequately tested.

Prevention and control

Prevention and control are as for typhus fever; no vaccine is available.

Control measures

The control methods used depend on the importance of the health problem. Individual or group treatment may be carried out where lice are merely a nuisance. Large-scale campaigns are recommended for the control of epidemic outbreaks of disease.

Head lice

Hygienic measures

Regular washing with soap and warm water and regular combing may reduce the numbers of nymphs and adults. However, washing will not remove the eggs, which are firmly attached to the hair. A special louse comb with very closely set fine teeth is effective in removing both adults and eggs (Fig. 4.19). Shaving the head is effective and this measure is sometimes adopted with young boys; however, it is often objected to and should not be insisted on.

Insecticides

Insecticide applications to the hair give the most effective control (*20-26*). They can be in the form of shampoos, lotions, emulsions or powders (Fig. 4.20; see also Table 4.3). Some pyrethroids are the most recommended products, since they do not cause the burning sensation of the scalp or other side-effects sometimes associated with other insecticides, such as lindane (*27*, *28*). Powder or dust formulations are usually less effective and less acceptable for use than lotions or emulsions. A soap formulation containing 1% permethrin can be applied as a shampoo (see box, p. 261).

How to make insecticidal dusts, shampoos and lotions

An insecticidal dust can be made by adding insecticide powder (wettable powder) to talcum powder to obtain the recommended dosage of active ingredient (in grams). An insecticidal shampoo is made similarly by adding insecticide powder or emulsifiable concentrate to hair shampoo with a neutral pH. An insecticidal lotion is made by mixing an emulsifiable concentrate with water or alcohol.

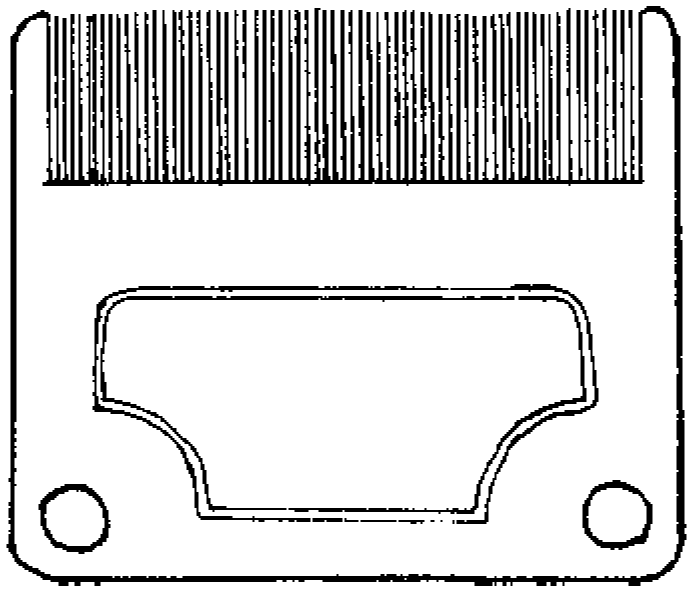


Fig. 4.19. A louse comb has very closely set fine teeth and is effective in removing head lice and their eggs.

Fig. 4.20. Hair can be treated with an anti-louse shampoo or lotion.

Table 4.3 Insecticides and formulations commonly used to control lice

Insecticide	Formulation and concentration (%)	
bioallethrin	lotion	0.3-0.4
	shampoo	0.3-0.4
	aerosol	0.6
carbaryl	dust	5.0
DDT	dust	10.0
	lotion	2.0
deltamethrin	lotion	0.03
	shampoo	0.03
jodfenphos	dust	5.0
lindane	dust	1.0
	lotion	1.0
malathion	dust	1.0

	lotion	0.5
permethrin	dust	0.5
	lotion	1.0
	shampoo	1.0
(+)-phenothrin	shampoo	0.2-0.4
	dust	0.3-0.4
propoxur	dust	1.0
temephos	dust	2.0

Insecticidal soap

The insecticidal soap bar is a recently developed inexpensive formulation of permethrin (1%) which is effective in killing head lice. It can also be used against the scabies mite (see p. 282).

How to use

The bar can be used as a shampoo. Apply to wet hair, work it into a lather and thoroughly massage into the scalp. Allow to remain on the head for 10 minutes, then rinse and dry the hair. Dead lice can be combed out over a towel. Repeat the procedure after three days. The hair will remain free of reinfestation for at least several weeks.

How to make

The bar, which is commercially available, can be produced locally for non-commercial purposes.

Ingredients	*%*
Crude raw coconut oil	57.0
Antioxidant	0.14
Permethrin	1.00
Mineral oil	8.86
Caustic soda solution	32.0
Natural clay	1.00

Premix the permethrin with the mineral oil at room temperature and add the mixture to the coconut oil in which the antioxidant has been dissolved. To this blend, add the caustic soda solution at ambient temperature, with rapid stirring. When all the caustic soda has been added, sprinkle the clay in and pour the emulsion into moulds, where the reaction continues for 12 hours.

The following day, cut the blocks into 40-g bars. If the bars are wrapped in polypropylene film and placed in an airtight box, the product will retain its effectiveness for more than two years. If they are packaged in a small plastic sandwich bag, or placed unwrapped in an airtight box, the shelf life is one year. If the product will be used up within a few weeks of manufacture, the lower-cost packaging is sufficient.

Impregnated mosquito nets

Head louse infestations disappear from people sleeping under mosquito nets impregnated with a long-lasting pyrethroid insecticide (*5*) (see Chapter 1 and p. 240).

Crab or pubic lice

Shaving the infested pubic hairs from the body has been replaced by the application of insecticidal formulations, as described for head louse control. In heavy infestations all hairy areas of the body below the neck should be treated.

Body lice

Individual treatment

Regular washing and changing of clothes usually prevents body louse infestations. In areas where water is scarce, washing facilities are lacking and people own only a single piece of clothing, this may be impractical. Another solution is to wash clothing and bedding with soap containing 7% DDT.

Soap and cold water are not sufficient to eliminate lice from clothing. Clothing must be washed in water hotter than 60 °C and should then be ironed if possible.

Group or mass treatment for disease control

The preferred method for mass treatment is the blowing of insecticidal powder between the body and underclothes. A suitable powder consists of talcum powder mixed with permethrin (0.5%), DDT (10%), lindane (1%) or another insecticide. Alternative insecticidal dusts, as shown in Table 4.3, can be used in the case of resistance. Because the dusts come into close contact with the body, it is important that the insecticides have a low toxicity to people and do not cause irritation.

An advantage of dusting powder is that it is easily transported and stored. Application can be made by any type of dusting apparatus, such as compressed-air dusters, plunger-type dusters and puff dusters (Fig. 4.21) (see p. 250), or by hand. It is important to explain the purpose of dusting to the people to be treated because the powder leaves clearly visible traces on clothing.

For individual treatment, about 30g of powder can be applied evenly from a sifter-top container over the surfaces of clothing that are in close contact with the body. Special attention should be given to the seams of underwear and other garments. To treat large groups of people about 50g of powder per person is needed. The powder is blown into the clothing through the neck openings, up the sleeves and from all sides of the loosened waist (Fig. 4.22). Socks, headwear and bedding should also be treated. One treatment should be sufficient but retreatment may be needed at intervals of 8-10 days if infestations persist.

The impregnation of clothing with a pyrethroid emulsion may provide long-lasting protection (*29*), the insecticide possibly remaining effective after 6-8 launderings.

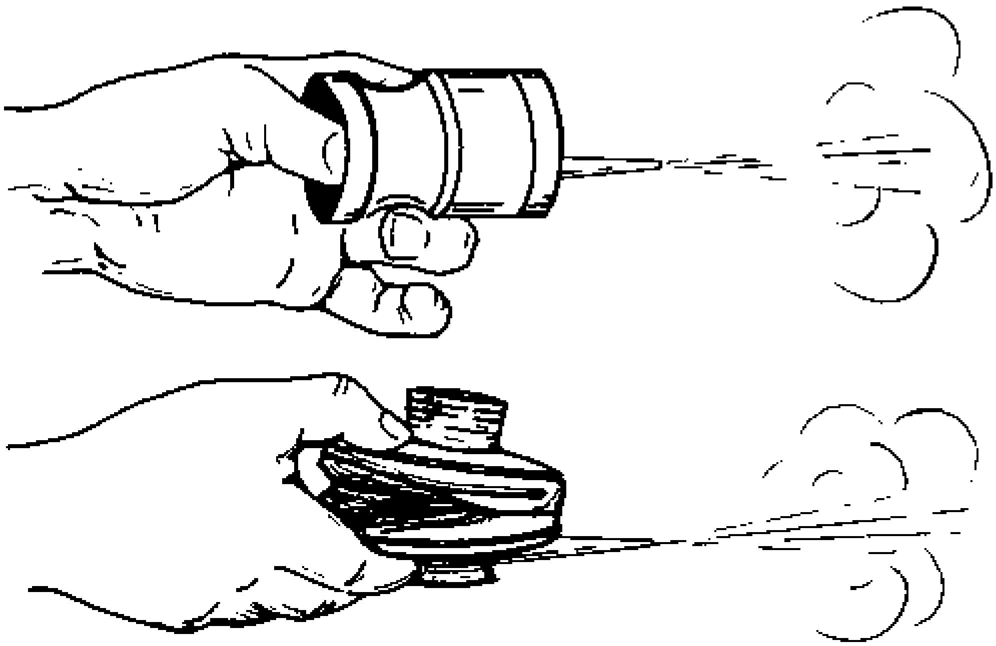


Fig. 4.21. Insecticidal dust can be applied to clothing with a hand-operated puff-duster (© WHO).
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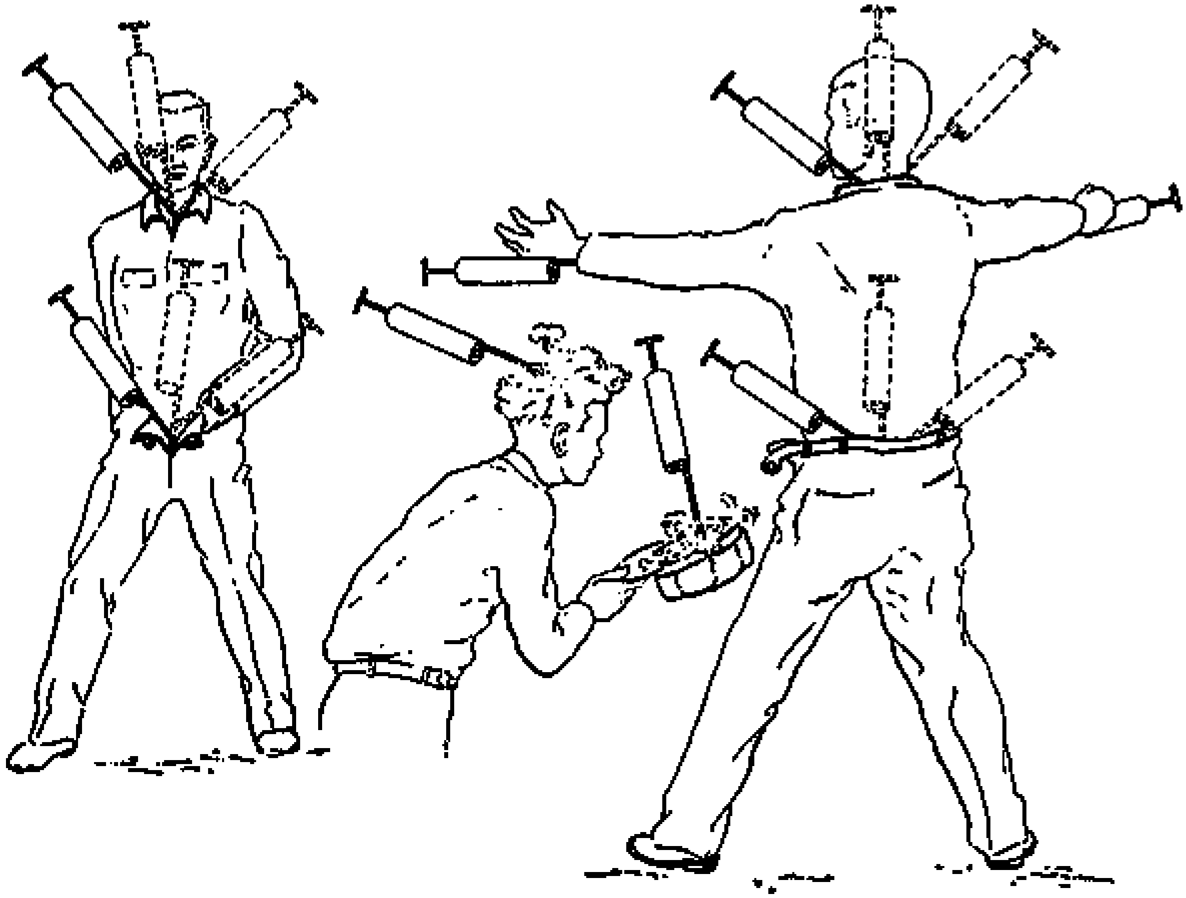


Fig. 4.22. Treating an individual with insecticidal dust using a plunger-type duster. (Reproduced from *Insect and rodent control*. Washington, DC, Departments of the Air Force, the Army and the Navy, 1956.)

Ticks

Ticks are arthropods that suck blood from animals and humans. They occur around the world and are important as vectors of a large number of diseases. Among the best-known human diseases transmitted by ticks are tick-borne relapsing fever, Rocky Mountain spotted fever, Q fever and Lyme disease. Ticks are also important as vectors of diseases of domestic animals and they can cause great economic loss. Two major families can be distinguished: the hard ticks (Ixodidae), comprising about 650 species, and the soft ticks (Argasidae), comprising about 150 species. Ticks are not insects and can easily be distinguished by the presence of four pairs of legs in the adults and the lack of clear segmentation of the body (Fig. 4.23).

Biology

Ticks have a life cycle that includes a six-legged larval stage and one or more eight-legged nymphal stages (Fig. 4.24). The immature stages resemble the adults and each of them needs a blood-meal before it can proceed to the next stage. Adult ticks live for several years, and in the absence of a blood-meal can survive several years of starvation. Both sexes feed on blood, the males less frequently than the females, and both can be vectors of disease. Disease organisms are not only passed from one host to another while blood is being taken: female ticks can also pass on certain disease agents to their offspring.

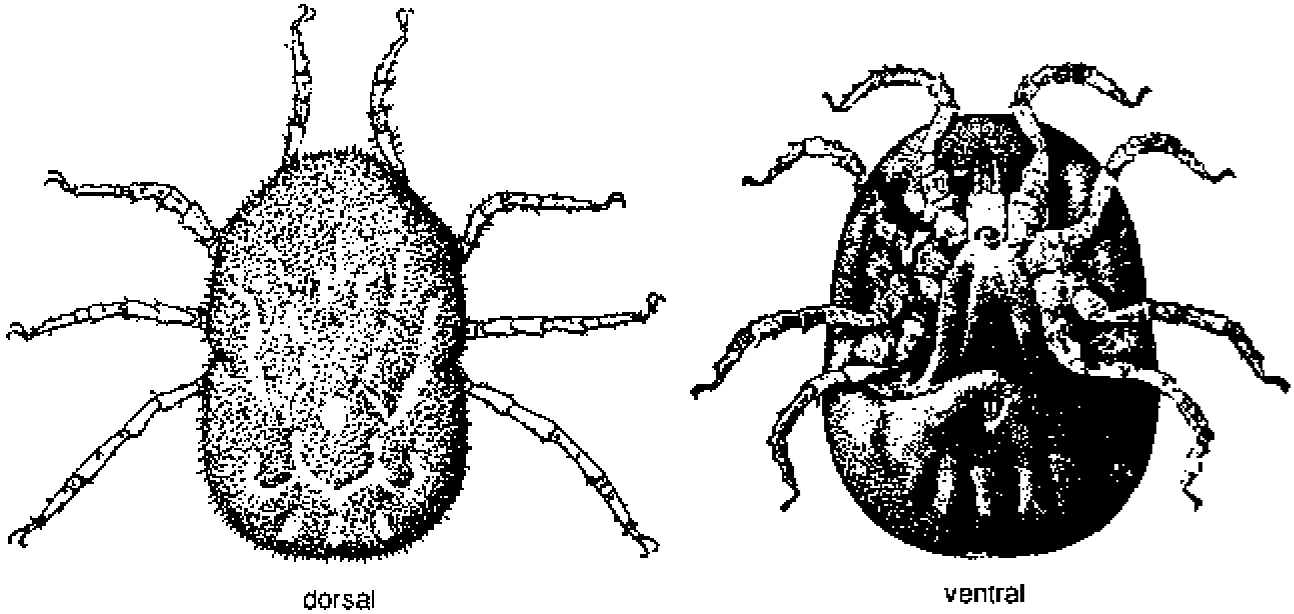


Fig. 4.23. A soft tick, *Ornithodoros moubata*, vector of relapsing fever in Africa (by courtesy of the Natural History Museum, London).

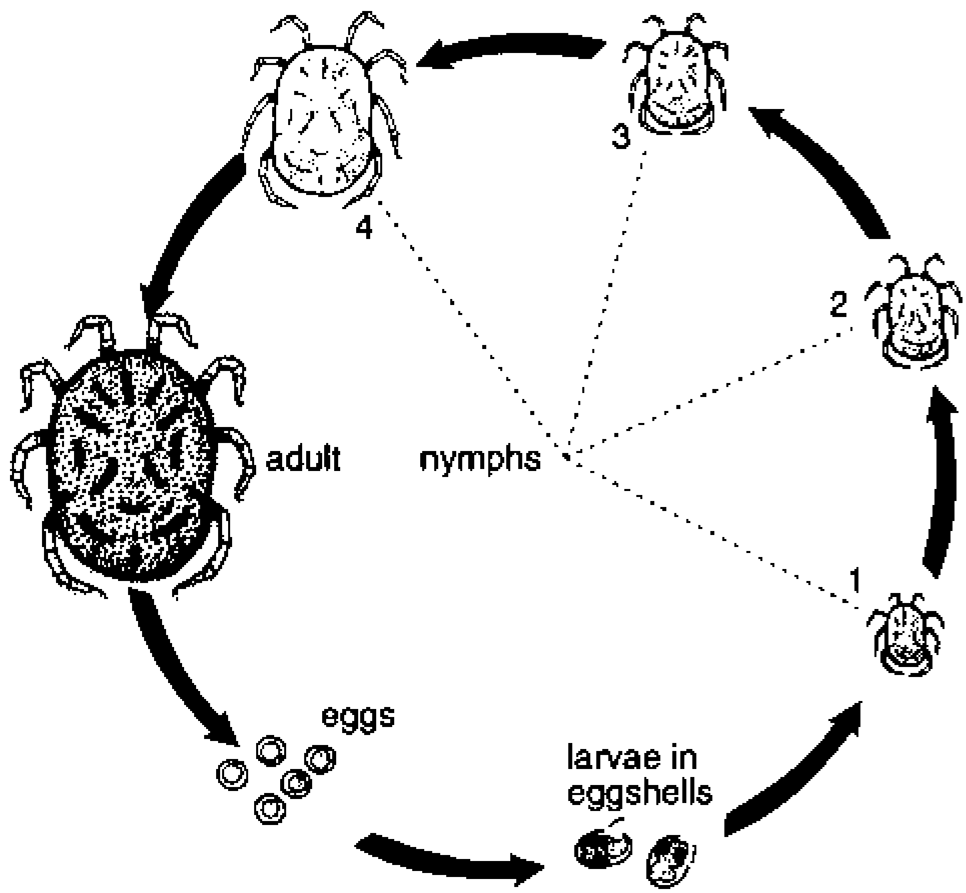


Fig. 4.24. Life cycle of the soft tick, *Ornithodoros moubata* (*30*).

Soft ticks

The adults are flat and oval in outline and have tough, leathery, wrinkled bodies. The mouthparts are situated underneath the body and are not visible from above. The eggs are laid in the places where the adults rest, such as cracks and crevices in the walls and floors of houses and in furniture. The larva, the five nymphal stages and the adults all actively search for hosts from which to take blood-meals. After feeding, which lasts about 30 minutes, they drop to the ground. Most species can survive for more than a year between blood-meals, and some for more than 10 years.

The soft ticks live apart from their hosts and are most common in the nests and resting places of the animals on which they feed. Some species, such as the chicken tick and the pigeon tick (*Argas* species) may feed on humans when the preferred hosts are not available.

Species that commonly feed on humans are found around villages and inside houses (Fig. 4.25). Their habits are comparable to those of bedbugs: ticks often emerge from hiding places at night to suck the blood of humans and animals. Some species are common on travel routes, in rest houses and camping sites, and in caves and crevices.

Hard ticks

The adult hard ticks are flat and oval in shape and between 3 and 23 mm long, depending on the species (Fig. 4.26). The mouthparts are visible at the front of the body, differentiating them from the soft ticks. In contrast to the soft ticks they have a shield-like plate or scutum behind the head on the back of the body, and there is only one nymphal stage (Fig. 4.27).

The eggs are deposited on the ground in large numbers. The larvae are very small, between 0.5 and 1.5 mm in length; they climb up vegetation, wait until a suitable host passes by, then climb on to it and attach themselves at a preferred feeding site, such as in the ears or on the eyelids.

After several days, when fully engorged, they drop to the ground, seek shelter and moult to the nymphal stage, which in turn seeks a blood-meal (Fig. 4.28), engorges, detaches itself and moults into an adult. The adult females climb up vegetation to wait for a suitable host, remaining on it for one to four weeks, then drop to the ground and seek shelter in cool places under stones and leaf litter, where they lay their eggs.

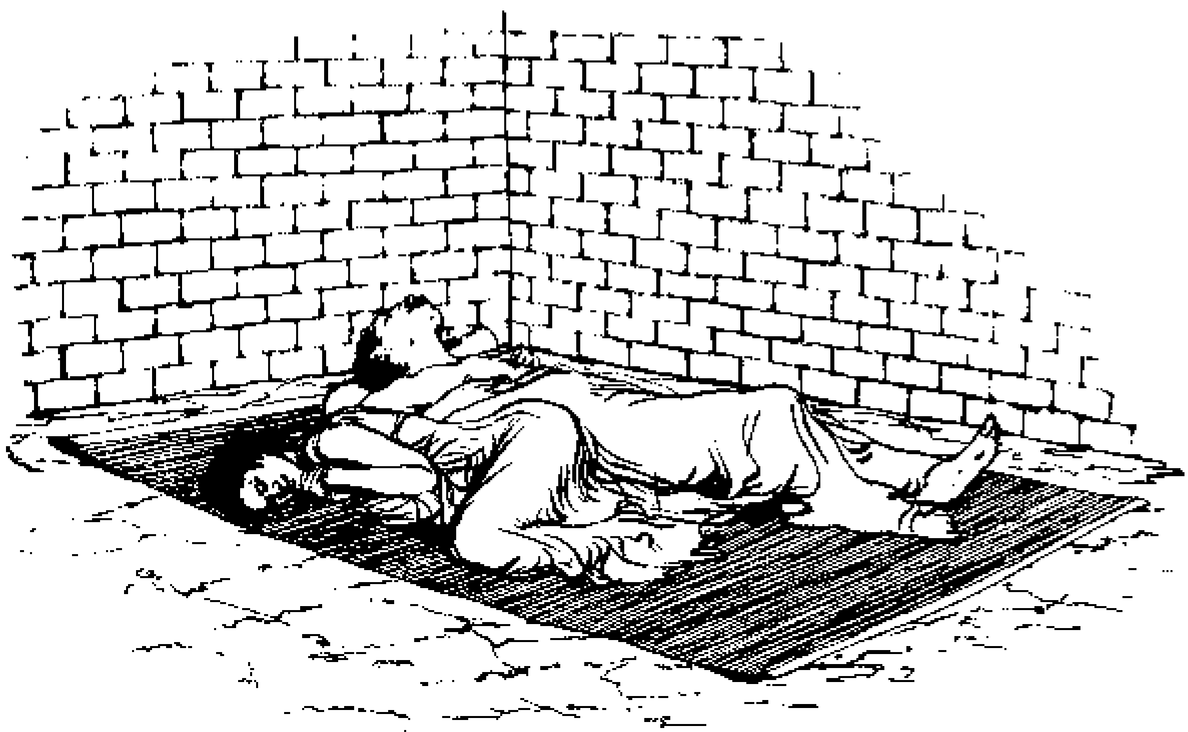
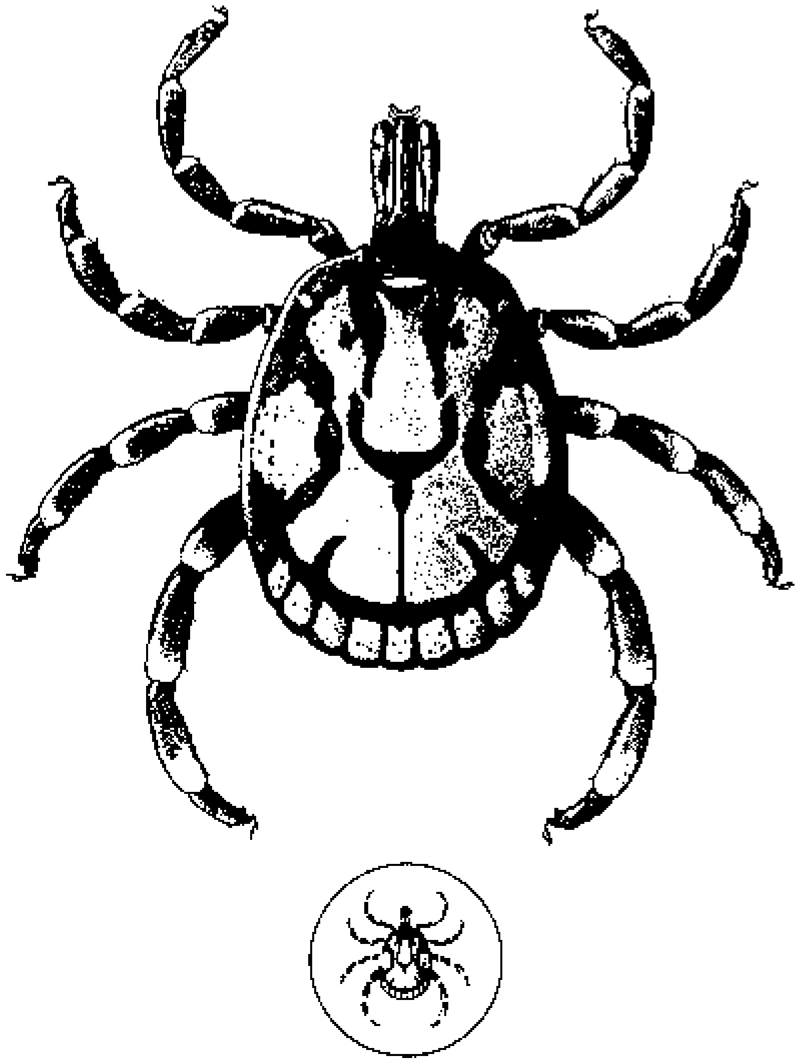
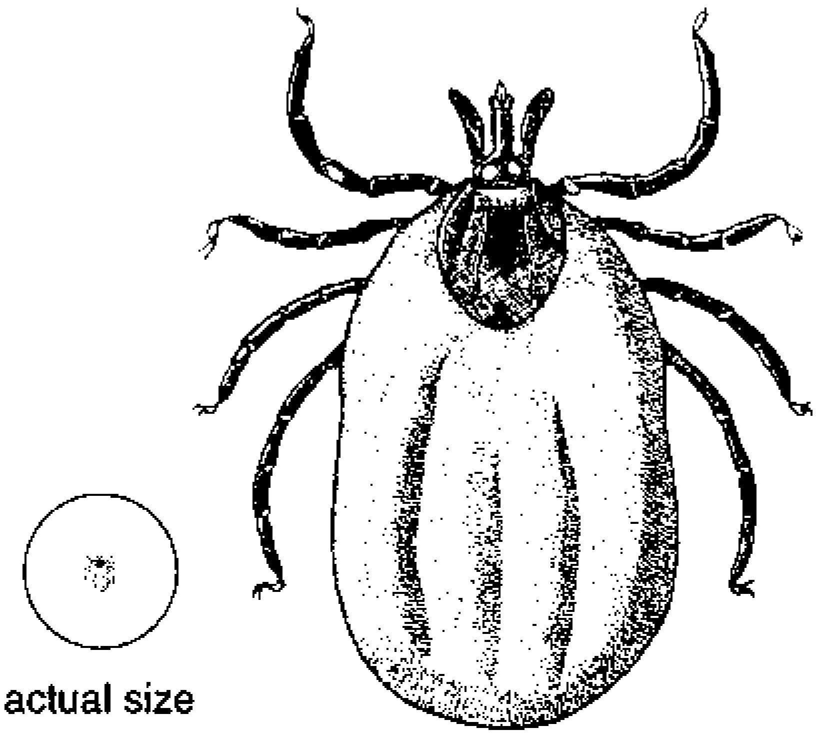


Fig. 4.25. *Ornithodoros* soft ticks are common in traditional-style mud-built houses with mud floors in some parts of Africa.

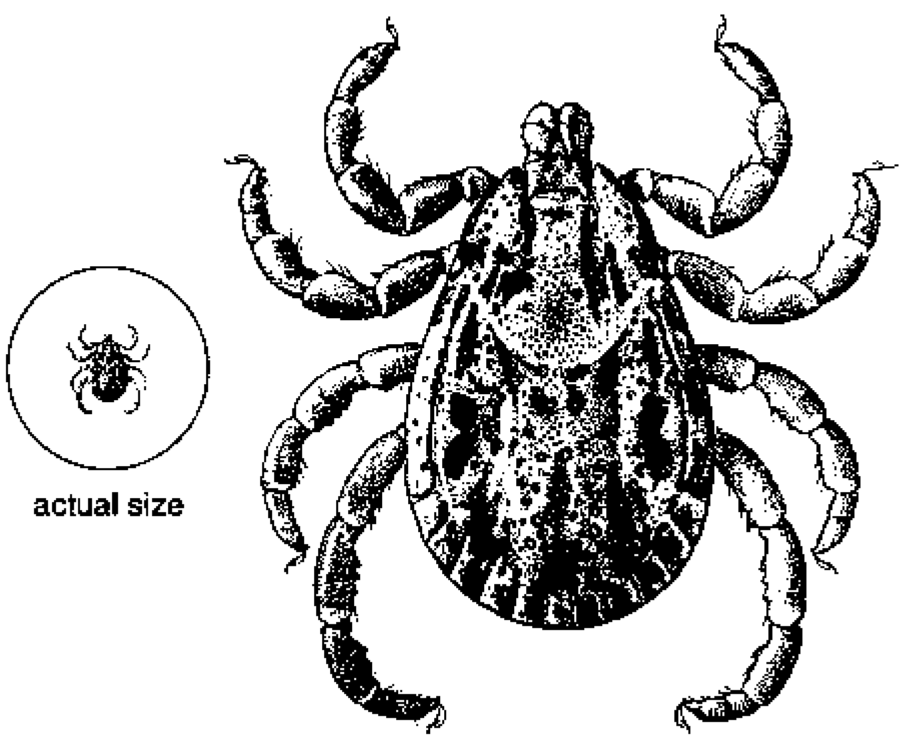
Fig. 4.26. Hard ticks.



(a) The bont tick, *Amblyomma hebraeum*, vector of spotted fever due to *Rickettsia conori* in southern Africa.



(b) The sheep tick, *Ixodes ricinus*, vector of tick-borne (Central European) encephalitis.



(c) The Rocky Mountain wood tick, *Dermacentor andersoni*, vector of spotted fever due to *Rickettsia rickettsii* in North, Central and South America (by courtesy of the Natural History Museum, London).

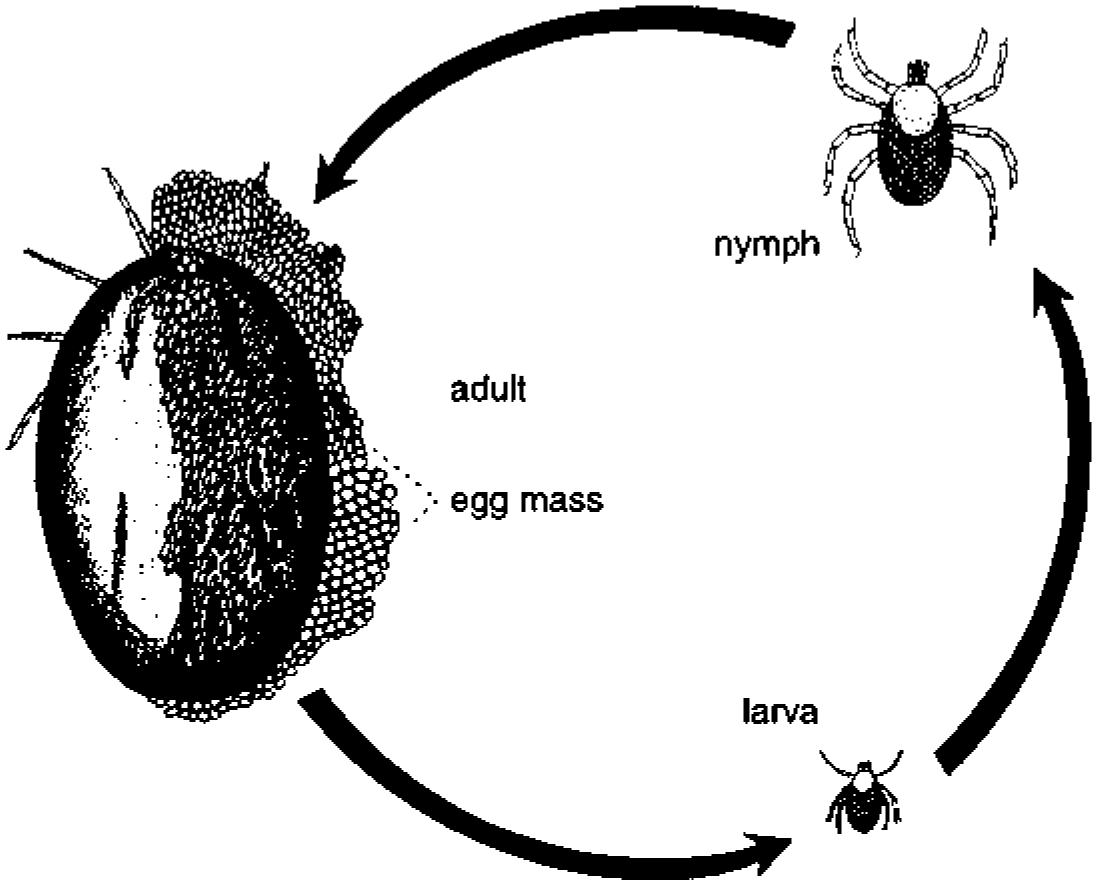


Fig 4.27 Life cycle of a hard tick (*Ixodes*) showing a female with a large mass of eggs, and a single nymphal stage (*30*).

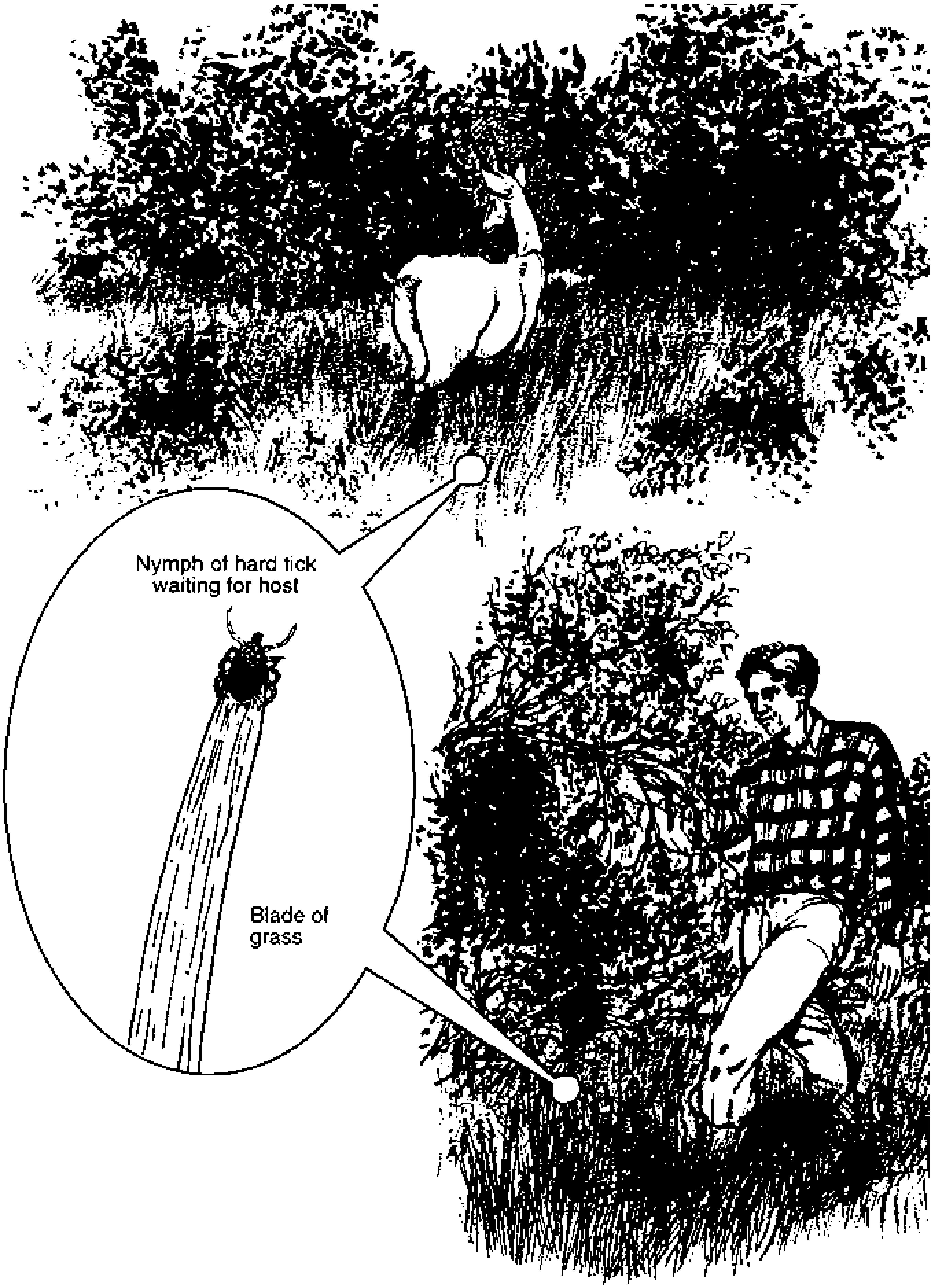

Nymph of hard tick
waiting for host
Blade of
grass

Fig. 4.28. A typical habitat of hard ticks, which normally feed on wild animals.

Most species of hard tick feed on three different hosts: one each for the larva, nymph and adult. However, some species feed on only one or two hosts. Because they remain attached to their hosts for several days, the hard ticks may be carried over large distances. The combination of feeding on different hosts and travelling considerable distances partly explains their importance as disease vectors.

Public health importance

Nuisance

Ticks can cause painful bites; heavy infestations, not uncommon in animals, can cause serious loss of blood.

Tick-borne relapsing fever

This disease is caused by a microorganism of the genus *Borrelia*. It is transmitted by biting soft ticks of the genus *Ornithodoros* in many countries in the tropics and subtropics and also in Europe and North America. The ticks usually feed quickly at night in or near houses, and then leave the host (*31*).

The disease causes bouts of fever alternating with periods without fever. Death occurs in about 2-10% of persons who are untreated.

Treatment

Treatment is possible with tetracycline or its derivatives.

Prevention

Prevention requires measures to control soft ticks and to avoid their bites.

Tick paralysis

Hard ticks inject into the body with their saliva certain toxins that can cause a condition in people and animals called tick paralysis. It appears 5-7 days after a tick begins feeding, paralysing the legs and affecting speaking ability, swallowing and breathing. It occurs worldwide and is most common and severe in children aged up to two years. Treatment involves removing the tick.

Tick-borne rickettsial fevers

This group of diseases is caused by closely related *Rickettsia* microorganisms transmitted by tick bites or contamination of the skin with crushed tissues or faeces of the tick.

- Spotted fever due to *Rickettsia rickettsii* occurs in Brazil, Canada, Colombia, Mexico, Panama and the USA.

• Spotted fever due to *R. sibirica* occurs in Japan, the Russian Federation and the Pacific.

• Spotted fever due to *R. conori* is found in the Mediterranean region, Africa and southern Asia.

• Spotted fever due to *R. australis* occurs in Queensland, Australia.

• Q fever, caused by *Coxiella burnetii*, has a worldwide distribution and is commonly present in abattoirs, meat-packing and meat-rendering plants, diagnostic laboratories, stockyards and poultry farms. It is transmitted to humans mainly by the consumption of milk and meat from contaminated cattle or the inhalation of dried infected tick faeces by people working with cattle.

Symptoms in humans are sudden fever persisting for several weeks, malaise, muscle and joint pains, severe headache and chills. A rash sometimes spreads over the entire body. Death may result in about 15-20% of persons if the disease is misdiagnosed or left untreated.

Treatment

Antibiotics such as tetracycline or chloramphenicol can be used.

Prevention

Tick bites should be avoided and attached ticks should be removed rapidly and carefully. Several hours of attachment are needed before the *Rickettsia* organisms can infect humans.

Lyme disease

Lyme disease (erythema chronicum migrans) is a severe and often debilitating condition caused by a spirochaete, *Borrelia burgdorferi*. Acute Lyme disease is a flu-like illness, characterized by an expanding red rash in about 50% of patients, accompanied by fever, fatigue, and muscle and joint pain. Weeks or even months after the infecting tick bite, patients may experience swelling and pain in large joints (knee, elbow), encephalitis, facial palsy, ocular lesions and carditis, irrespective of whether a rash occurred in the acute phase. Later, perhaps years after the bite, there may be cartilage erosion (arthritis) and neuromuscular dysfunction (Fig. 4.29). Lyme disease occurs principally in northern temperate regions of the world, including China, Europe, the USA and the former USSR.

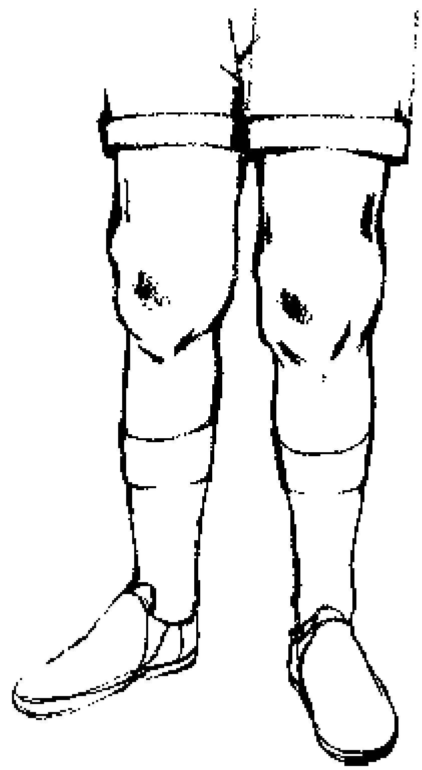


Fig. 4.29. A typical symptom of Lyme disease is swelling and pain in the large joints, such as the knees, and chronic arthritis.

Transmission

The disease is transmitted mostly by *Ixodes* ticks, commonly in the summer when the nymphs are abundant. Small rodents, especially mice, serve as reservoirs of infection while large mammals serve principally as hosts maintaining tick populations. The larvae acquire infection while feeding on mice, and nymphs or adults can transmit spirochaetes during subsequent blood-meals. In the northern temperate zone, where it occurs most intensely, Lyme disease has become more common as deer populations have increased and as this critical host has adapted to living in closer proximity to people. In many areas, Lyme disease is acquired in the suburban residential environment (*32*).

Treatment

Further development of the disease in adults may be reduced or prevented by treatment with tetracycline or its derivatives for 2-4 weeks, and in children by treatment with penicillin.

Prevention

Prevention requires avoidance of tick habitats and bites, and vector control. Personal protection may be possible by the use of repellents on the skin and clothing in tick-infested areas. The removal of attached ticks within 24 hours may prevent spirochaete transmission. Prophylactic antibiotic therapy may be desirable following the bite of an infected tick. New molecular assays are commercially available for detecting the spirochaetes in tick samples.

Tularaemia

Tularaemia, also known as rabbit fever, deerfly fever and Ohara disease, is caused by the infectious agent *Francisella tularensis*. The symptoms, which vary according to how the agent enters the body, include headache, chills, fever and the swelling of lymph nodes. The disease occurs in Europe, Japan, North America and the former USSR.

Transmission

Transmission takes place through the bites of ticks and deerflies (see Chapter 1) or as a result of handling infected animals such as rabbits and other game. Hunters and forest workers are at the highest risk of infection.

Treatment

Antibiotics such as streptomycin can be used to treat the disease.

Prevention

Tick bites and tick habitats should be avoided, impermeable gloves should be worn when skinning and dressing game animals, wild game meat should be thoroughly cooked, and untreated drinking-water should be avoided in areas where the disease occurs.

Tick-borne viral encephalitides

This is a group of viral diseases causing acute inflammation of the brain, spinal cord and meninges. The symptoms vary in severity with the type of disease. Many infections do not result in disease. Severe infections may cause violent headaches, high fever, nausea, coma and death.

- Far Eastern tick-borne encephalitis is found in the far east of the former USSR.

- Central European tick-borne encephalitis occurs in Europe from the Urals to France.

- Louping ill is a disease of sheep in the United Kingdom which sometimes affects people.

Transmission and prevention

These diseases are transmitted by biting ticks and by the consumption of milk from infected animals. No specific treatment is available but vaccines have been developed against some of the diseases. Prevention requires avoidance or rapid removal of ticks.

Principal hard tick vectors

Usually various tick species act as vectors for any one disease and their importance

varies from region to region.	
Disease	**Vector**
Lyme disease	Deer tick, *Ixodes dammini*
Spotted fever due to:	
Rickettsia rickettsii	American dog tick, *Dermacentor variabilis*
R. sibirica	Asiatic wood tick, *Dermacentor silvarum*
R. conori	Brown dog tick, *Rhipicephalus sanguineus*
R. australis	Wattle tick, *Ixodes holocyclus*
Q fever	Lone star tick, *Amblyomma americanum*
Tularaemia	American rabbit tick, *Haemaphysalis leporis-palustris*
Far Eastern tick-borne encephalitis	Taiga tick, *Ixodes persulcatus*
Central European tick-borne encephalitis	Castor bean tick, *Ixodes ricinus*
Kyasanur Forest disease	A tick of birds and monkeys, *Haemaphysalis spinigera*
Colorado tick fever	American wood tick, *Dermacentor andersoni*
Crimean-Congo haemorrhagic fever	A tick of birds and mammals, *Hyalomma marginatum*

Other viral diseases

Kyasanur Forest disease occurs in parts of India.

Omsk haemorrhagic fever is found in south-western Siberia; it causes severe disease and death in muskrat handlers; it is mainly waterborne, although it is found in hard ticks.

Colorado tick fever is a moderately severe disease that occurs in western North America.

Crimean-Congo haemorrhagic fever is an acute, often severe and fatal disease found in parts of Africa, Asia and Europe.

Control measures

Self-protection

Avoidance

Fields and forests infested with ticks should be avoided if possible. In Africa, bites by the soft tick *Ornithodoros moubata*, the vector of relapsing fever, can be prevented by avoiding old camp sites and by not sleeping on floors of mud houses. Beds, especially metal ones, may provide some protection because the ticks have difficulty in climbing the legs. However, they may still be able to reach hosts by climbing up the walls.

Repellents

Effective repellents that prevent ticks from attaching to the body include deet, dimethyl phthalate, benzyl benzoate, dimethyl carbamate and indalone (*33*). These substances can be applied to the skin or clothing. On the skin, repellents often do not last more than a few hours because of absorption and removal by abrasion. On clothing they last much longer, sometimes for several days (*34*). For more information on repellents, see Chapter 1.

Clothing

Clothing can provide some protection if, for example, trousers are tucked into boots or socks and if shirts are tucked into trousers. Clothing should be removed and examined for the presence of ticks after a tick-infested area has been visited.

Impregnated clothing

People who frequently enter tick-infested areas should consider impregnating their clothing by spraying (*35*, *36*) or soaking with a pyrethroid insecticide such as permethrin or cyfluthrin. Ticks crawling up trousers or shirts are quickly knocked down. Thus, not only is biting prevented but the ticks are also killed. Pyrethroid treatment of clothing is additionally effective against mosquitos for a month or longer (*34*). Information on how to treat clothing with a pyrethroid insecticide is given in Chapter 1.

Removal of attached ticks

During and after visits to tick-infested areas it is important to examine the body frequently for ticks. They should be removed as soon as possible because the risk of disease transmission increases with the duration of attachment.

A tick should be removed by pulling slowly but steadily, preferably with forceps to avoid contact between the fingers and the tick's infective body fluids. The tick should be grasped as close as possible to where the head enters the skin, so as not to crush it, and care should be taken not to break off the embedded mouthparts, as they may cause irritation and secondary infection. Some veterinarians may have a special tool for quick removal of ticks from dogs.

The following methods may induce soft ticks to withdraw their mouthparts: touching with a hot object such as a heated needle tip; dabbing with chloroform, ether or some other anaesthetic. With hard ticks these methods only work immediately after biting because they are attached with a saliva cement that prevents them from quickly withdrawing their mouthparts. In areas where ticks are only a nuisance they can be coated with oil, paraffin, vaseline or nail varnish to prevent them from obtaining oxygen. Hard ticks then dissolve the cement so that they can withdraw their mouthparts, but this may take several hours. However, these methods are not recommended in areas where ticks are vectors of disease, as they work too slowly and may cause ticks to regurgitate into wounds, injecting disease organisms. In such circumstances it is recommended to pull the ticks out immediately, even if the head is left in the wound.

Application of insecticides to animals

Domestic animals are often hosts to ticks that can feed on humans and transmit disease to people and animals. Insecticides applied directly to the bodies of these animals in the form of dusts, sprays, dips or washes can be very effective. Pour-on formulations are applied over the animals' backs. The insecticide (a pyrethroid) is distributed over the whole body by tail and other movements.

Insecticidal powders or dusts can be applied by means of a shaker, puff-duster or plunger-type duster. Insecticidal sprays are applied with hand-compression sprayers. The same insecticides and dosages can be used as for the control of fleas (see Table 4.2). It is particularly important to treat the back, neck, belly and the back of the head.

Plastic collars impregnated with an insecticide for the control of fleas in dogs and cats (see Table 4.2) are only partially effective against most species of tick.

Spraying insecticides in houses and resting places for animals

Ticks can be killed by insecticides sprayed on floors in houses, porches, verandas, dog kennels and other places where domestic animals sleep. Suitable residual sprays are indicated in Table 4.4 (see also p. 246).

Houses infested with soft ticks (*Ornithodoros*) can be sprayed with lindane ($0.2 g/m^2$) or another insecticide formulation. Special care must be taken to treat the hiding and resting places of ticks in cracks and crevices in walls, floors and furniture. Residual house-spraying against malaria mosquitos has often resulted in a reduction in the numbers of ticks (see also p. 241).

Table 4.4 Insecticidal formulations used against ticks

Application method	Insecticide formulation
Dipping, washing or spray-on	malathion (5%), dichlorvos (0.1%), carbaryl (1%), dioxathion (0.1%), naled (0.2%), coumaphos (1%)
Insecticidal powder (dust)	carbaryl (5%), coumaphos (0.5%), malathion(3-5%), trichlorphon (1%)
Residual spray on floors, etc.	oil solutions or emulsions of DDT (5%), lindane(0.5%), propoxur (1%), bendiocarb (0.25-0.48%), pirimiphos methyl (1%), diazinon (0.5%), malathion(2%), carbaryl (5%), chlorpyrifos (0.5%)
Ultra-low-volume fogging (area spraying)	organophosphorus insecticides, carbamate compounds and pyrethroids
Flea and tick collars for dogs and cats	dichlorvos (20%), propoxur (10%), propetamphos(10%), permethrin (11%)

Impregnated mosquito nets

Soft ticks that habitually feed indoors on sleeping persons can be controlled with impregnated bednets (*5*) (see also p. 240 and Chapter 1).

Community protection

Large-scale control activities are sometimes carried out in recreational areas or in areas where ticks transmit tick-borne diseases. It is often economical and effective to integrate several methods into a comprehensive control strategy (*37*). Possible components of an integrated strategy are as follows:

- *Surveillance*: sampling to identify tick habitats where control is needed.

- *Vegetation management*: physical or chemical measures to reduce and isolate tick habitats.

- *Host management*: removal or exclusion of host animals.

- *Targeted chemical control*: pesticide applications against ticks, targeted at the tick host or habitat.

- *Cultural practices*: lifestyle changes to limit exposure to ticks.

- *Personal protection*: protective clothing; repellents; checking for and removing of ticks.

Area spraying with insecticides

Spraying ticks directly in their natural habitats in forests and fields may control outbreaks of certain tick-borne diseases (e.g. Lyme disease (*38*) and tick-borne encephalitides). Large areas may be treated by ultra-low-volume spraying of liquid acaricide concentrates from fixed-wing aircraft or helicopters. Small areas may be sprayed by means of motorized knapsack sprayers or mist-blowers, applying either ultra-low-volume formulations or formulations of water-based emulsions or wettable powders. Control lasts for a month or longer, depending on conditions and the size of the treated area. Suitable biodegradable insecticides are shown in Table 4.4 (*39-44*).

Vegetation management

In, for example, parks and camp sites, ticks can be controlled by removal of the vegetation serving as their habitat (*37*, *45*). This can be done by cutting, mowing or applying herbicides.

Host management

Tick populations can be reduced by removing the animals on which they usually feed. Fences can be used to exclude larger animals such as deer (*37*).

Insecticide-treated nesting material

Nest-building rodents serve as natural reservoirs or critical hosts for many vector-borne infections, including Lyme disease, several of the tick-borne encephalitides, and others. One host-targeted vector control strategy uses insecticide-impregnated nesting material directed at the rodent reservoirs of Lyme disease spirochaetes. In the USA, white-footed mice serve as the principal reservoirs. Larval deer ticks become infected while feeding on these mice, and nymphs derived from mouse-fed larvae become infected vectors. Mice actively harvest soft material for their nests; when they incorporate cotton nesting material treated with 7-8% permethrin, their tick infestations are virtually eliminated.

This method has been used in residential areas bordering woodlands and parklands in the northern USA to reduce the abundance of infected nymphal ticks (*46*, *47*). The treated nesting material is protected in dispensing tubes (4 cm in diameter by 20 cm in length) and is placed about every 10 m in mouse habitats. The impregnated material is made using a patented method of soaking cotton in a permethrin emulsion and then drying it.

Clearly, mice must find and use the nesting material if this method is to work, and failures have been reported (*48*). However, when used properly, such a host-targeted treatment can significantly reduce the abundance of infected ticks, using up to 20 times less active ingredient and at less cost than insecticidal spray treatments. Community-wide programmes, where all properties in a neighbour-hood receive treatment, have proved most effective.

Mites

Mites are very small, ranging from 0.5 to 2.0 mm in length; there are thousands of species, of which many live on animals. Like ticks, they have eight legs and a body with little or no segmentation. In most species there are egg, larval, nymphal and adult stages. The immature stages are similar to the adults but smaller.

Some mites are important vectors of rickettsial diseases, such as typhus fever due to *Rickettsia tsutsugamushi* (scrub typhus) and several viral diseases. Mites can present a serious biting nuisance to humans and animals. Many people show allergic reactions to mites or their bites. Certain mites cause a condition known as scabies. The major mite pests discussed here are:

- biting mites (vectors of scrub typhus);
- scabies mites;
- house dust mites.

Biting mites

Numerous species of mite are parasitic on mammals and birds and occasionally attack humans. Their bites can cause irritation and inflammation of the skin. One group, the trombiculid mites, transmits typhus fever due to *R. tsutsugamushi* in Asia and the Pacific. Only the trombiculid mites are described here, the biology and life cycle of other biting mites being similar.

Biology

Adult trombiculid mites are about 1-2 mm in length, bright red or reddish-brown in colour, and of velvety appearance. The nymph is similar but smaller. The larvae, also called chiggers, are very small, being only 0.15-0.3 mm in length (Fig. 4.30). Neither the adults nor the nymphs bite animals or humans; they live in the soil and feed on other mites, small insects and their eggs. The larvae, however, feed on skin tissue.

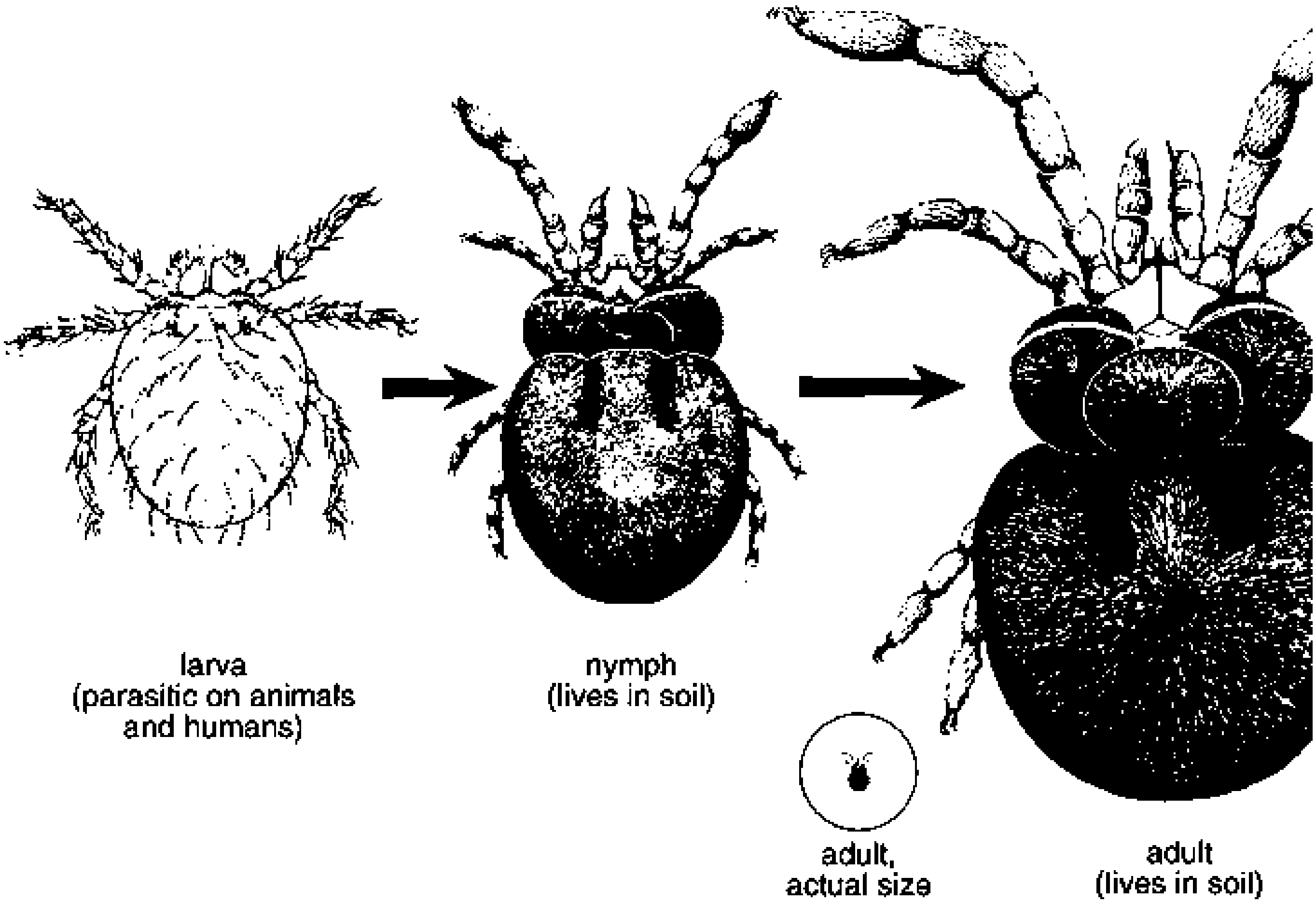


Fig. 4.30. The biting mite (*Trombicula* species). Reproduced from reference *49* with the permission of the publisher. Copyright Macmillan Publishing Company.

After emerging from the eggs the larvae crawl onto grasses or low-lying vegetation and leaf litter to wait for an animal or human host. They attach themselves to the skin of reptiles, birds, mammals and humans walking or resting in the habitat. On humans they seek out areas where clothing is tight against the skin, the waist and ankles being the parts most commonly attacked.

The larvae remain attached to the skin of the host for between two days and a month, depending on the species. They then drop to the ground and enter the soil to develop into the harmless nymphal and adult stages.

Distribution

Mites have a very patchy distribution over small areas because of their special requirements. The nymphs and adults need certain soil conditions for their survival and development while the larvae require host animals, such as wild rats, other small rodents and birds. Suitable habitats are found in grassy fields, shrubby areas, forests, abandoned rice fields and cleared forests. The mites are also found in parks, gardens, lawns and moist areas alongside lakes and streams.

The larvae wait on leaves or dry grass stems until an animal or human passes by. People usually become infested after walking or standing in mite-infested areas. Bamboo bushes are favoured by the mites in the tropics and subtropics.

Public health importance

Nuisance

The bites can cause severe itching, irritation and inflammation of the skin (scrub itch). They usually occur on the legs. At the site of a bite the skin swells slightly and turns red. In the centre a red point indicates the location of the chigger. Because chiggers are invisible to the naked eye, most people are not aware of their presence until bites appear.

Scrub typhus

Biting mites can transmit a number of rickettsial and viral diseases to humans but only the most important one, scrub typhus, is discussed here. It is caused by *Rickettsia tsutsugamushi* and causes an acute fever, severe headache and lymphadenopathy.

At the site of attachment of the infected mite a primary skin lesion consisting of a punched-out ulcer covered by an eschar commonly develops before the onset of the fever attack. Depending on a number of factors the mortality rate is in the range 1-60%.

Distribution and transmission

Scrub typhus occurs mostly in low-lying rural areas of Asia and Australia (Fig. 4.31). It was very common in troops during the Second World War. The disease occurs most frequently in people visiting or working in mite-infested areas in scrub, overgrown terrain, forest clearings, reforested areas, new settlements and newly irrigated desert regions.

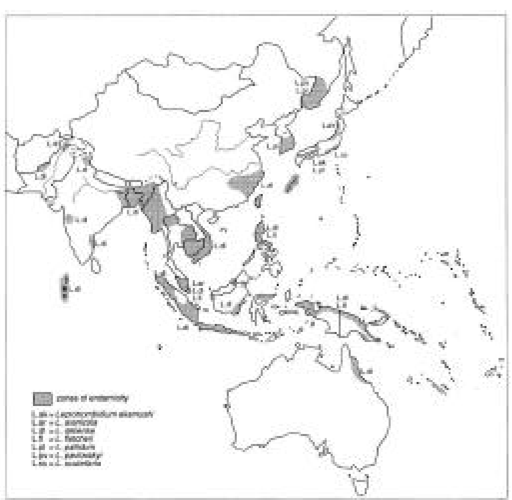


Fig. 4.31. Areas in south-east Asia and the western Pacific where scrub typhus occurs, 1996 (© WHO).

Treatment, prevention and control

Infected persons can be treated with tetracycline or its derivatives. Prevention is possible by avoiding contact with mites. The chiggers can be controlled by spraying of residual insecticides in woodland or bush areas, although this is expensive.

Control measures

Prevention of bites

Biting can be prevented by avoiding infested terrain and applying repellents to skin and clothing. Openings in clothing can be treated by hand or spray. A band of 1-3 cm is normally sufficient. Benzyl benzoate, dimethyl phthalate, deet, dimethyl carbamate and ethyl hexanediol are effective repellents. Under conditions of frequent exposure the best protection is given by impregnated clothing and by tucking trousers inside socks. Where vegetation is low it is sufficient to treat socks and the bottoms of trouser legs. The clothing can be treated with one or a combination of the above repellents or with a pyrethroid insecticide (see Chapter 2) providing more long-lasting protection, even after one or two washes. Deet and dimethyl phthalate have been shown to be the most effective repellent compounds against some mite species (*50*, *51*).

Removal of vegetation

The control of mites by killing them in their habitats is very difficult because of the patchy distribution of their populations. If it is possible to identify the patches of vegetation that harbour large numbers of larval mites (mite islands), it may be advantageous to remove them by burning or cutting and then to scrape or plough the top-soil. Mowing grass or weeds in these areas also helps. Such measures are recommended in the vicinity of camp sites and buildings.

Residual spraying of vegetation

Where the removal of vegetation is not possible, mite islands can be sprayed with residual insecticide. The spraying of vegetation up to a height of 20 cm around houses, hospitals and camp sites is effective against grass mites in Europe. The insecticides can be applied as fogs with ultra-low-volume spray equipment. Some suitable compounds are diazinon, fenthion, malathion, propoxur and permethrin (*52*).

Scabies mite

The scabies mite, *Sarcoptes scabiei*, causes an itching condition of the skin known as scabies. Infestations with scabies are common worldwide.

Biology

The mites are between 0.2 and 0.4 mm long and virtually invisible to the naked eye (Fig. 4.32). Practically the whole life cycle is spent on and in the skin of humans. In order to feed and lay eggs, fertilized females burrow winding tunnels in the surface of the skin. The tunnels are extended by 1-5 mm a day and can be seen on the skin as very thin twisting lines a few millimetres to several centimetres long.

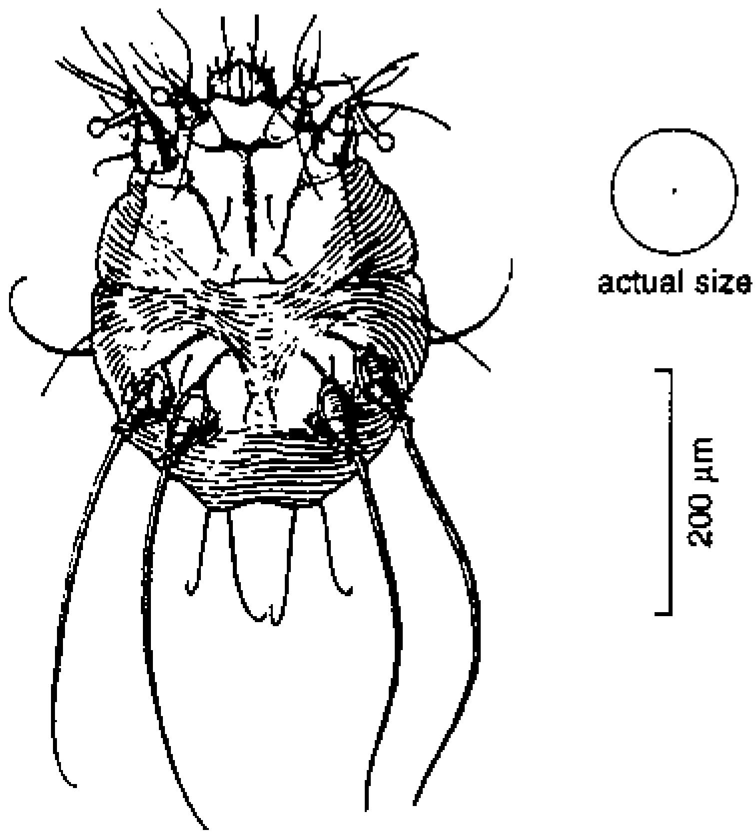


Fig. 4.32. The scabies mite. With a length of 0.2-0.4 mm it is hardly visible to the naked eye (by courtesy of the Natural History Museum, London).

Development from egg to adult may take as little as two weeks. The females may live on people for 1-2 months. Away from the host they survive for only a few days.

Scabies mites are commonly found where the skin is thin and wrinkled, for instance between the fingers, on the sides of the feet and hands (Fig. 4.33), the bends of the knee and elbow, the penis, the breasts and the shoulder blades. In young children they may also be found on the face and other areas.

Public health importance

Transmission

Scabies is usually transmitted by close personal contact, as between people sleeping together, and during sexual intercourse. Dispersal mostly takes place within families and if one family member becomes infested it is likely that all the others will follow suit. The mites are unlikely to be acquired by someone sleeping in a bed previously used by an infested person, but may be passed on in underclothes.

Distribution

Scabies occurs throughout the world in persons of all ages and social groups. In some developing countries up to a quarter of the population may be affected. It is most common in young children. Outbreaks of scabies are frequently reported from places where people live in overcrowded, unhygienic conditions (e.g. refugee camps) and where there is poor hygiene, such as in poorly maintained prisons and nurseries.

Fig. 4.33. A heavy infestation of scabies mites in the skin of the wrist (*53*).

Symptoms

Initially a small, slightly elevated, reddish track appears, which itches intensely. This is followed by the formation and eventual rupture of papulae and tiny vesicles on the surfaces of the skin. Scratching causes bleeding and leads to the spread of the infestation. Vigorous and constant scratching often results in secondary infections, giving rise to boils, pustules and eczema.

A typical scabies rash can develop in areas of the body not infested with mites. This occurs mainly on the buttocks, around the waist and on the shoulders, and is an allergic reaction.

In newly infested persons the itching and rash do not appear until about 4-6 weeks after infestation but in previously infested individuals the rash develops in a few days.

A rare form of the disease is Norwegian scabies, which is associated with an immense number of mites and with marked scales and crusts, particularly on the palms and soles. It appears to occur more frequently among people with immuno-deficiency disorders (especially HIV infection) than among immunocompetent patients (*54-56*).

Confirmation

Scabies infection can be confirmed by scraping the affected skin with a knife, transferring the material to a glass slide, and examining it for mites under a microscope. The application of mineral oil facilitates the collection and examination of scrapings. Another method involves applying ink to infested skin areas and then washing it off, thus revealing the burrows.

Treatment

It has recently been discovered that ivermectin, which is used in the treatment of onchocerciasis and lymphatic filariasis, is also suitable for the treatment of scabies infections. It is administered in a single oral dose of 100-200 mg per kg of body weight (*57-59*).

Conventional treatment methods aim to kill the mites with insecticide (see Table 4.5). Information on how to make and apply the formulations is provided on pp. 259-261. After successful treatment, itching continues for some time but eventually it disappears completely. Treatment of all family members is necessary to prevent reinfestation.

Most treatments provide a complete cure but sometimes a second application within 2-7 days is needed. Overtreatment should be avoided because of the toxicity of some of the compounds.

Commonly used insecticides are lindane (10% lotion), benzyl benzoate (10% lotion), crotamiton (10% cream) and permethrin (5% cream). The latter is now considered the treatment of choice because of its high efficacy and the low risk of associated side-effects (*55*, *60-62*).

Table 4.5 Formulations of insecticides which can be applied as creams, lotions or aqueous emulsions for use against scabies

Insecticide	Formulation
benzyl benzoate	20-25% emulsion
sulfur	in oily liquid
lindane	1% cream or lotion
malathion	1% aqueous emulsion
permethrin	1% soap bar or 5% cream

Application method

The formulation must be applied to all parts of the body below the neck, not only to the places where itching is felt. It should not be washed off until the next day. Treated persons can dress after the application has been allowed to dry for about 15 minutes.

House dust mite

House dust mites (*Dermatophagoides* complex) have a worldwide distribution (Fig. 4.34). They are very small (0.3 mm) and live in furniture, beds, pillows and carpets where they feed on organic debris, such as discarded skin scales and scurf. The inhalation of house dust laden with mites, mite faeces, and other debris and fungi associated with them produces allergic reactions in many people, such as asthma and inflammation of the nasal mucous membrane. Large numbers of allergens produced by house dust mites may be in the air after bed-making.

In temperate climates, mites occur throughout the year mainly in beds and carpets. Mites living on living room floors show a seasonal peak in density in late summer and early autumn.

Some other mites causing similar reactions in humans live among stored products, grains and animal feeds.

Prevention and control

The density of house dust mite allergens can be assessed by a test which measures the concentration of mite excreta (guanine) in dust (*63*).

Mites and associated fungi can be controlled by decreasing the humidity in rooms, improving ventilation and removing dust. Bedrooms and living rooms should be aired regularly, or other measures should be taken to reduce dampness. The shaking of bedclothes and frequent washing of sheets and blankets reduces the availability of food and therefore the number of mites. Vacuum cleaning of beds, carpets and furniture is also effective. General insecticides used for pest control are not effective but a special product containing benzyl benzoate is available, which destroys mites when applied to mattresses, carpets and upholstery (*63*, *64*).

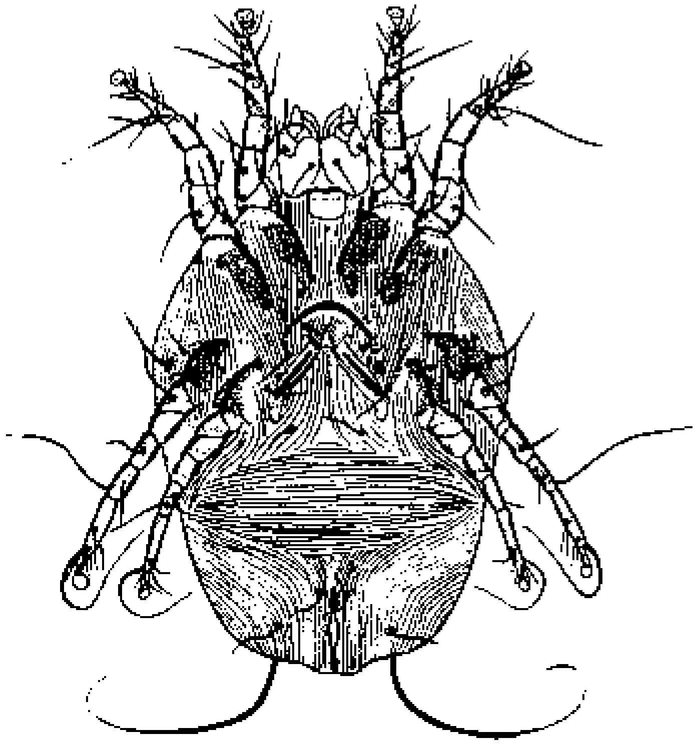


Fig. 4.34. The house dust mite (*Dermatophagoides pteronyssinus*) (by courtesy of the Natural History Museum, London).

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Chapter 5 - Cockroaches

Unhygienic scavengers in human settlements

Cockroaches are among the most common pests in many homes and other buildings. At night they search for food in kitchens, food storage places, rubbish bins, drains and sewers. They are pests because of their filthy habits and bad smell. Some people may become allergic to cockroaches after frequent exposure. Cockroaches can sometimes play a role as carriers of intestinal diseases, such as diarrhoea, dysentery, typhoid fever and cholera.

Biology

Cockroaches are insects, flattened from top to bottom, usually with two pairs of wings folded flat over the back (Fig. 5.1). Most species rarely fly but they walk very fast. The colour usually varies from light brown to black. The species vary from 2-3 mm to over 80 mm in length.

Of over 3500 identified species only a few are of importance to people because they have adapted to living in buildings. The most common species are:

• *Periplaneta americana*, the American cockroach, which occurs around the world. It is 35-40 mm in length and is a shiny reddish to chocolate brown colour (Fig. 5.2a). The egg case measures 8-10 mm and contains 16 eggs.

• *Periplaneta australasiae*, the Australian cockroach, which occurs mainly in tropical and subtropical areas. It is similar to the American cockroach, but smaller (31-37 mm long) and darker (Fig. 5.2b). It has a pale yellow stripe on each forewing extending for about one-third its length. The egg case contains about 22-24 eggs.

• *Blatta orientalis*, the Oriental cockroach, found mainly in cool temperate regions. It is blackish and 20-27 mm long (Fig. 5.2c). The egg case is 10-12 mm long and contains 16-18 eggs.

• *Supella longipalpa*, the brown-banded cockroach, which occurs around the world. It is 10-14 mm long and has yellow and brown bands (Fig. 5.2d). The egg case is 4-5 mm in length and contains about 16 eggs.

• *Blattella germanica*, the German cockroach, found in most parts of the world.

It is light yellowish brown and 10-15 mm in length, making it one of the smallest domestic cockroaches (Fig. 5.2e). The female usually carries the egg case until shortly before the young come out. The egg case is light in colour, about 7-9 mm long and contains about 40 eggs.

Life cycle

Cockroaches are relatively primitive, having only three stages in their life cycle: egg, nymph and adult (Fig. 5.3). The female deposits its eggs in groups surrounded by a leathery, bean-shaped egg case or capsule called an ootheca. Some species, such as the German cockroach, carry the ootheca for several weeks attached to the back end of the body. Most others deposit the ootheca after one or two days. Oothecae are very distinctive and can frequently be used to determine the species present. Depending on the species, temperature and humidity, the eggs hatch after 1-3 months.

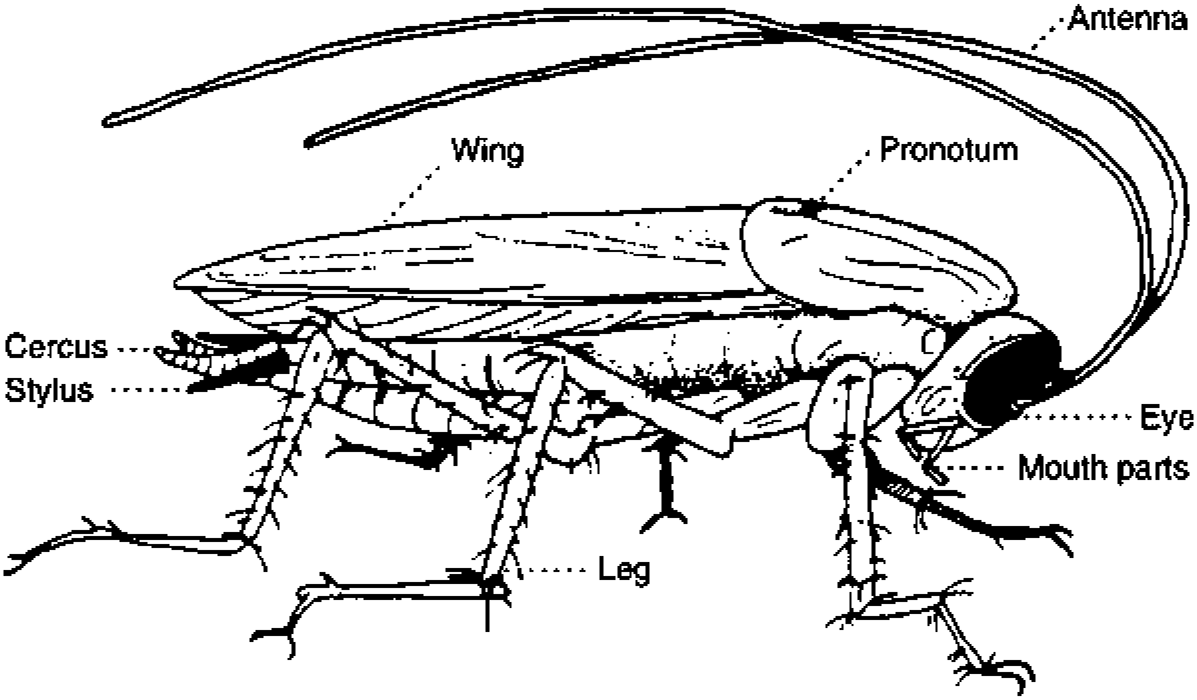

Fig. 5.1. Side view of a cockroach (*Blattella germanica*) (© WHO).

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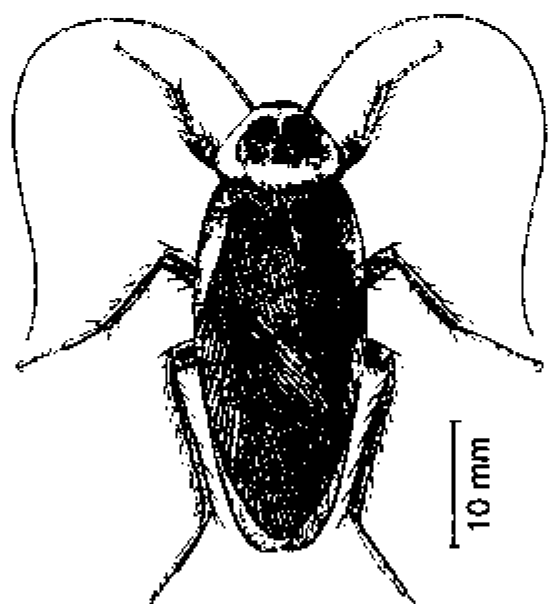
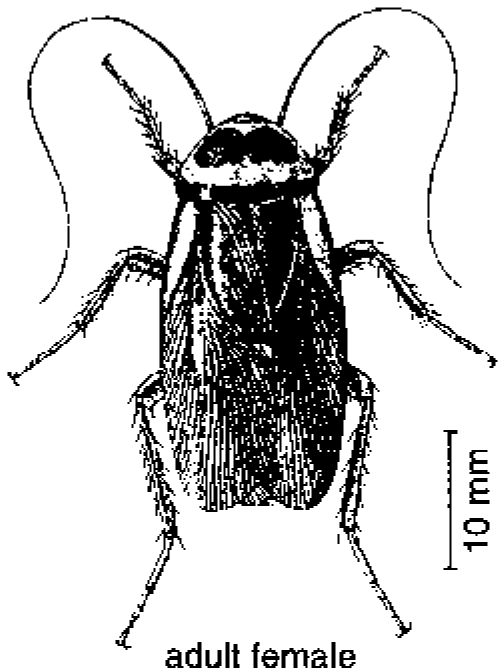
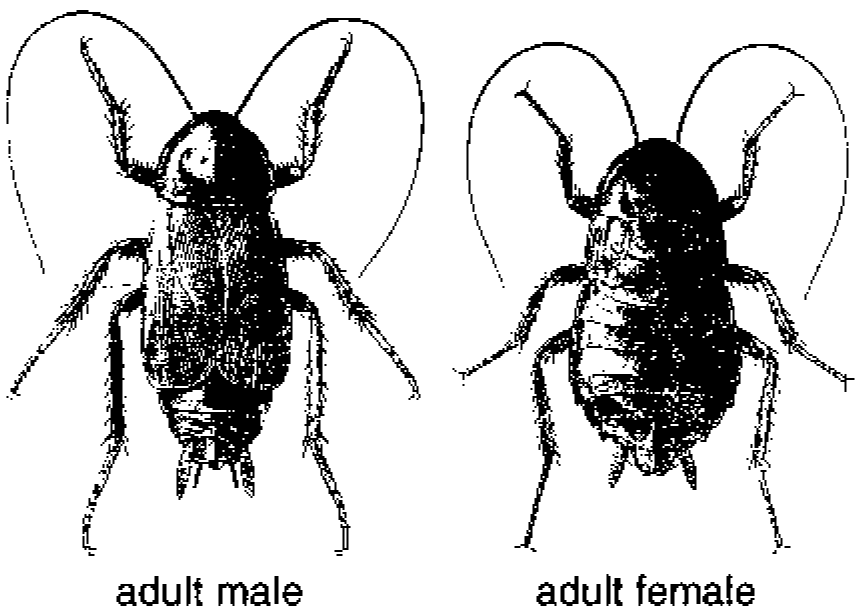
Fig. 5.2. The most common cockroach species:



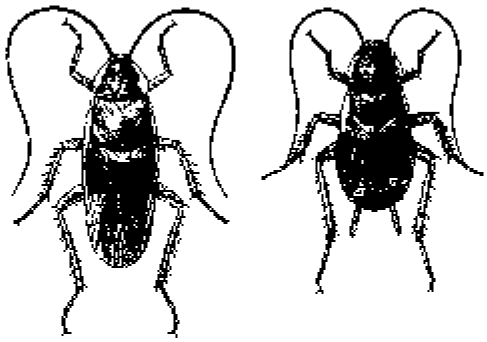
(a) American cockroach, *Periplaneta americana*;



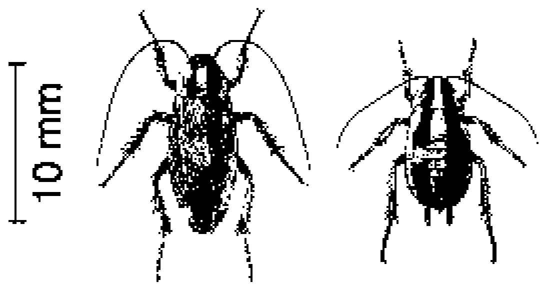
(b) Australian cockroach, *Periplaneta australasiae*;



(c) Oriental cockroach, *Blatta orientalis*;



(d) brown-banded cockroach, *Supella longipalpa*;



(e) German cockroach, *Blattella germanica* (by courtesy of the Natural History Museum, London).

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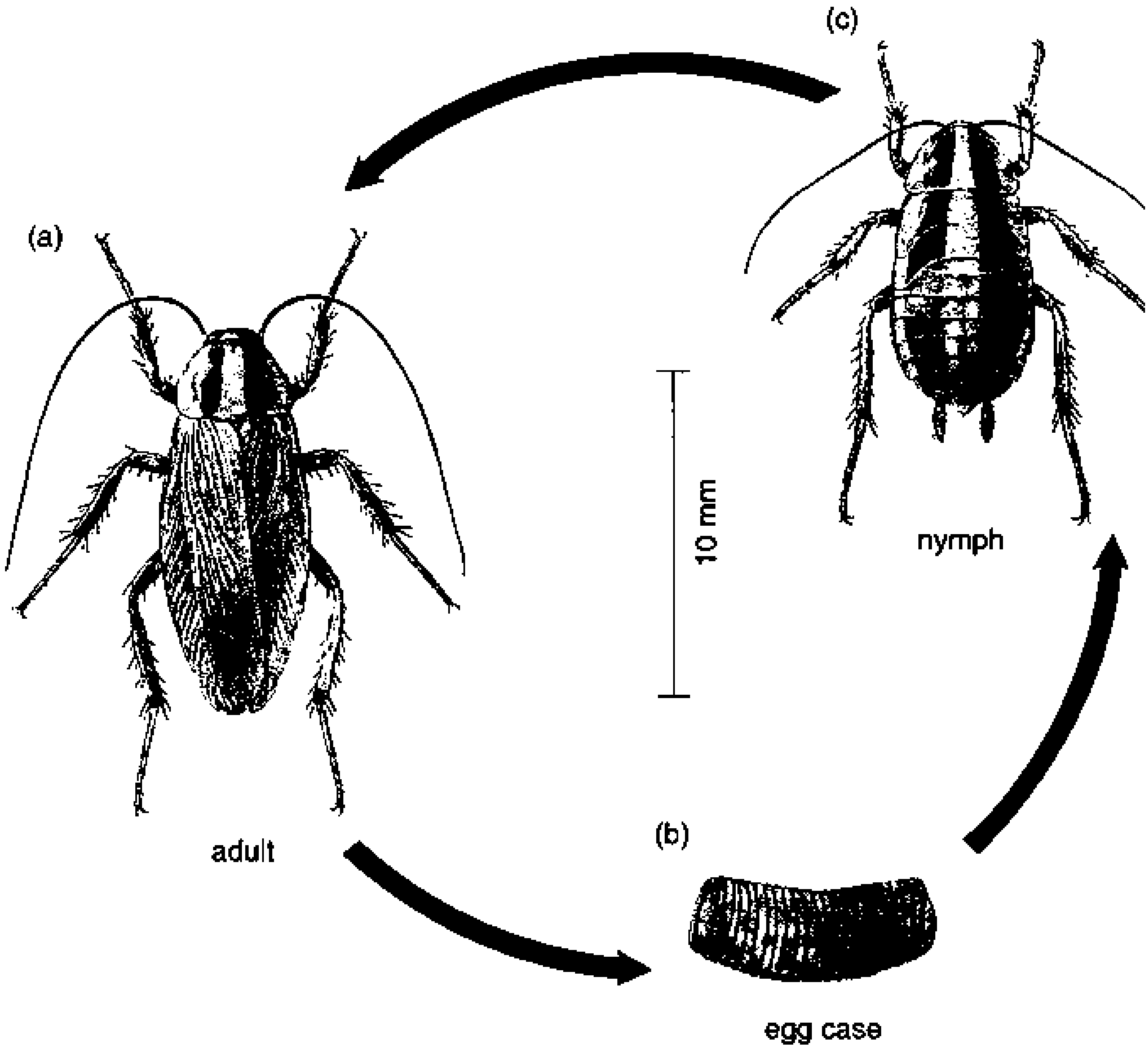


Fig. 5.3. Life cycle of the German cockroach (by courtesy of the Natural History Museum, London).

The young cockroaches, or nymphs, are wingless, and usually only a few millimetres long; they are white on hatching but darken within a few hours. They grow in stages by repeatedly shedding the cuticle or skin. They are fully grown after several months to more than a year, depending on the species. The adults may or may not possess wings, consisting of one outer leathery pair beneath which is folded a membranous pair.

Behaviour

Pest cockroaches live in close association with people (*1*, *2*). They are tropical in origin but in the temperate zones most species live in parts of houses and other buildings where warmth, moisture and food are adequate.

Cockroaches usually live in groups. They are mostly active at night; in the daytime they hide in cracks and crevices in walls, door frames and furniture, and in secure places in bathrooms, cupboards, steam tunnels, animal houses, basements, televisions, radios and other electric devices, drains and sewer systems. If the lights are turned on in an infested kitchen at night the cockroaches will run from dishes, utensils, working surfaces and the floor towards shelter.

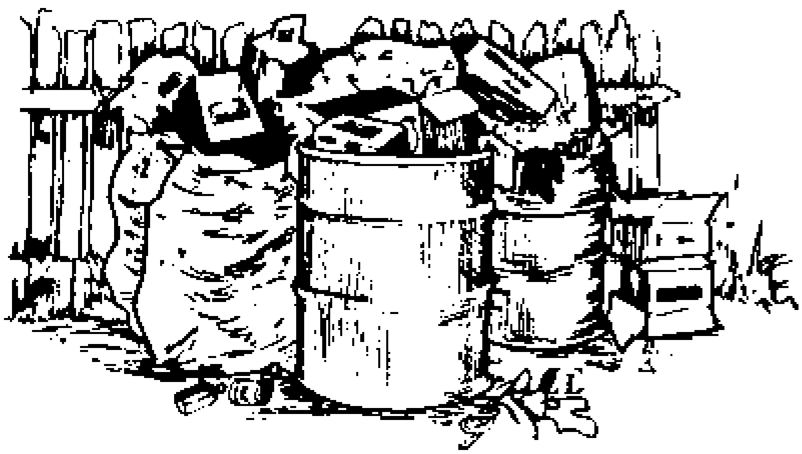


Fig. 5.4. Uncovered garbage bins offer an excellent environment for cockroaches to develop (© WHO).

Cockroaches eat a great variety of food, including all food used for human consumption (Fig. 5.4). They prefer starchy and sugary materials. They sip milk and nibble at cheese, meats, pastry, grain products, sugar and sweet chocolate. They also feed on cardboard, book bindings, ceiling boards containing starch, the sized inner lining of shoe soles, their own cast-off skins, dead and crippled cockroaches, fresh and dried blood, excrement, sputum, and the fingernails and toenails of babies and sleeping or sick persons.

Dispersal

Mass migrations have been reported for some species, apparently resulting from overcrowding. The migrants move into new areas by crawling or flying. They commonly enter houses in boxes of bottled drinks and bags of potatoes, onions or other foodstuffs that have become infested in poorly maintained foodstores. Long-distance transportation of the pests can occur on aircraft, ships or other vehicles.

Public health importance

Nuisance

Cockroaches are important pests because they spread filth and ruin food, fabrics and book-bindings. They disgorge portions of their partially digested food at intervals and drop faeces. They also discharge a nauseous secretion both from their mouths and from glands opening on the body which give a long-lasting, offensive cockroach smell to areas or food visited by them.

Diseases

Cockroaches move freely from building to building or from drains, gardens, sewers and latrines to human habitations. Because they feed on human faeces as well as human food they can spread germs that cause disease (Fig. 5.5) (*2*, *3*). Cockroaches are not usually the most important cause of a disease, but like houseflies they may play a supplementary role in the spread of some diseases. They are proven or suspected carriers of the organisms causing:

- diarrhoea
- dysentery
- cholera
- leprosy
- plague
- typhoid fever
- viral diseases such as poliomyelitis.

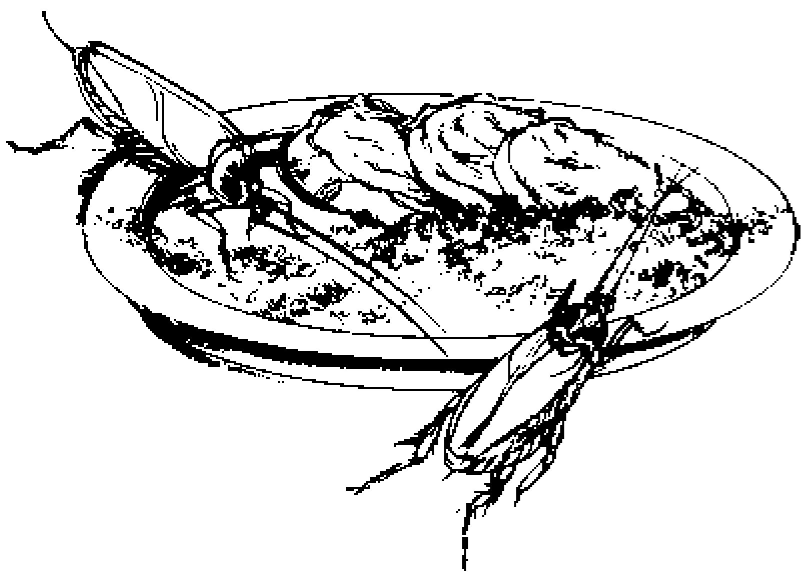


Fig. 5.5. Cockroaches can spread disease by contaminating human food with germs they pick up in latrines, garbage dumps, etc.

In addition they carry the eggs of parasitic worms and may cause allergic reactions, including dermatitis, itching, swelling of the eyelids and more serious respiratory conditions (*4*).

Control measures

Effective control is easier in temperate climates (where cockroach populations cannot survive outdoors in winter) than in humid and warm areas. The key to control is cleanliness, which may be difficult in houses where there are children and domestic animals. In isolated homes, control is easier to achieve than in apartments where cockroaches may have easy access from adjacent quarters. Reinfestation occurs from outdoors in warm areas, or along heating ducts and water pipes in apartments, or from groceries or luggage brought from cockroach-infested areas. Cockroaches may even sometimes be found in very clean houses, but are unlikely to establish colonies.

The presence of several sizes of nymphs and oothecae is an indication of a well-established colony. Infestations can be detected by searching behind skirting-boards, boxes, furniture and other common hiding places. At night, cockroaches are easily detected using light.

Heavy infestations of cockroaches can be dealt with by chemical control measures, followed by environmental management to deprive the insects of food and shelter. Low numbers can be effectively controlled by baits or traps.

Environmental management

Cleanliness and hygiene

Food should be stored in tightly covered containers in screened cabinets or refrigerators (Fig. 5.6). All areas have to be kept clean so that no fragments of food or organic matter remain. Rubbish bins should be securely covered and emptied frequently, preferably daily.

Basements and areas underneath buildings should be kept dry and free of accessible food and water.

Reduction of accessibility

Groceries, laundry, dirty clothing, egg crates and furniture should be checked before being taken into a building.

In some instances, accessibility to buildings can be reduced by closing gaps in floors and door frames. Openings for drain water and sewer pipes, drinking-water and electricity cables should also be closed (Fig. 5.7).

Chemical control

Cockroaches are difficult to control with insecticides for several reasons, one of which is that they may become resistant to commonly used compounds. Moreover, many insecticides are repellent to them and are therefore avoided (*5*). Chemical control gives only temporary relief and, wherever possible, it should be accompanied by environmental sanitation and house improvement (*6*).

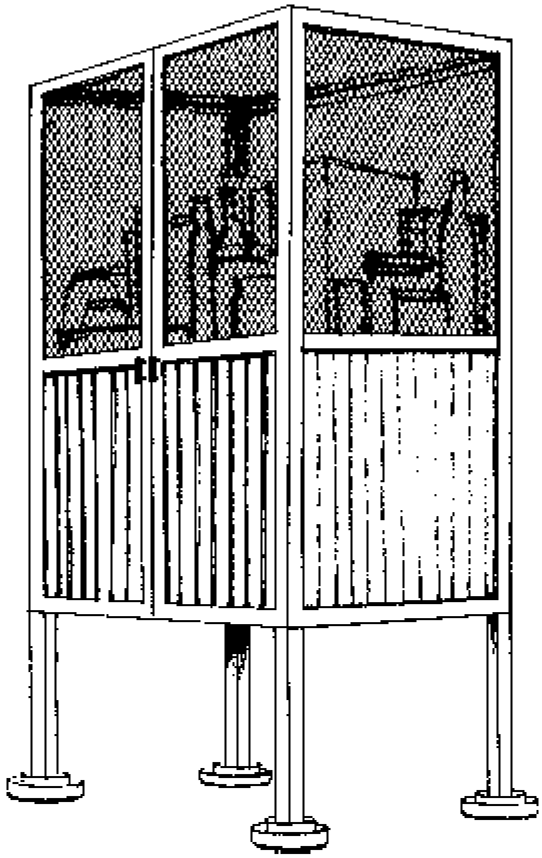


Fig. 5.6. Food can be protected in a cockroach-, fly- and ant-proof cabinet.

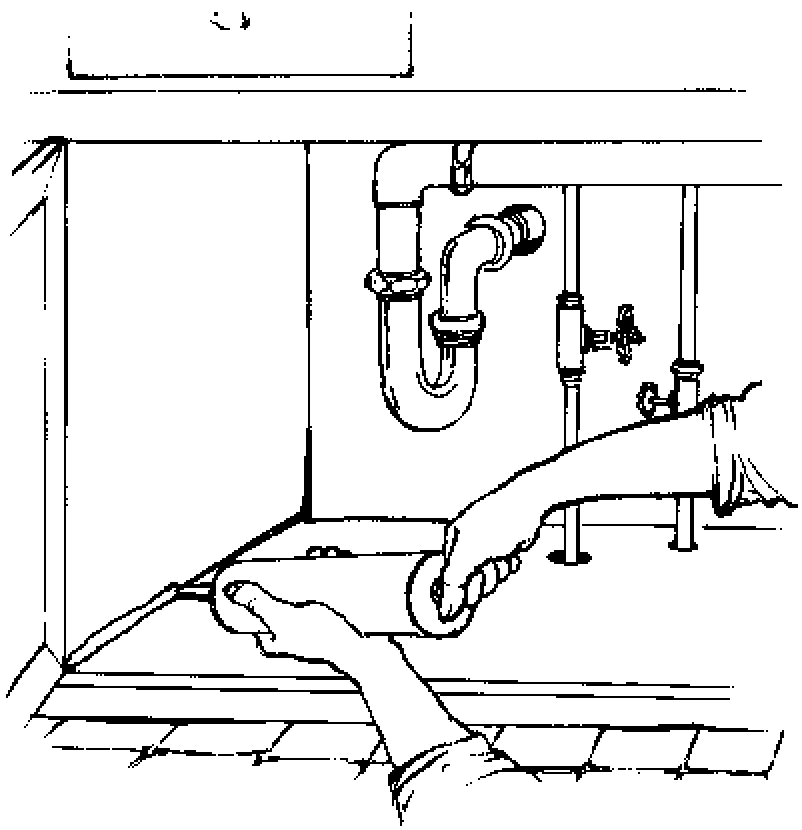


Fig. 5.7. Reduce accessibility to cockroaches by sealing openings, cracks and crevices.

Insecticides are applied to the resting and hiding places as residual sprays and insecticidal dusts. Such applications are effective for periods ranging from several days to months, depending on the insecticide and the substrate on which it is deposited. Insecticides can also be combined with attractants as toxic baits.

Resistance

The German cockroach is resistant to several organochlorine, organophosphorus, carbamate and pyrethroid insecticides (*7*). The Oriental cockroach, the American cockroach and the large brown cockroach (*Periplaneta brunnae*) have developed little resistance, mainly to DDT and chlordane. Recently, the American cockroach has been found to be resistant to trichlorfon in China and the large brown cockroach to diazinon in the USA.

Application

Areas to be treated

Areas to be treated include kitchens, galleys, behind and along skirting-boards, in and around sinks, in or under cupboards, under chairs and tables, in utility cabinets, near refrigerators and ice boxes, under loose floor coverings, food preparation areas, ducts, pipes, sewers and manholes. Food storage areas in restaurants, warehouses and other commercial establishments should be treated.

Frequency of treatment

How long the deposits of insecticide remain effective depends on a number of factors, such as the thoroughness of application, the speed of re-infestation, the chemical used, the dosage and formulation applied, the type of surface to which it is applied, the temperature and humidity, and the amount of wearing or rubbing off that occurs. Insecticides generally last longer on painted than on unpainted surfaces and longer on wood than on brick or block surfaces.

Frequent washing of a treated surface or coatings of dust or grease can render an insecticide useless. A single treatment rarely results in eradication. For most species, additional treatments may be necessary at monthly intervals to kill newly hatched nymphs or to prevent reinfestation.

Safety and precautions

Care should be taken to avoid food contamination. Avoid treating areas where children may come into contact with the residue. In special situations, such as the treatment of zoos or pet shops, residual sprays or dusts cannot be used. In such cases it may be possible to apply a limited quantity of chemical with a brush. Alternatively, a chemical with low toxicity to mammals and birds, such as boric acid powder or silica aerogel, may be used.

Some formulations may stain fabrics, wallpaper, floor tiles or other household materials. Information should be obtained on this subject before treatment is carried out.

Residual sprays

Residual sprays are usually applied with household plunger-type sprayers or hand-compression air sprayers. The sprayers are equipped with pinstream nozzles to spray the insecticide into cracks and areas that are hard to reach. A broader fan spray is useful for areas that are more accessible. The spray should moisten the surface thoroughly but not to the point of water running off or dripping.

A volume of four litres of diluted insecticide per 100 m^2 sprayed in swaths 30-50 cm wide is often appropriate. The insecticide can be applied with a paint brush when other equipment is not available. Thorough treatment of runways and harbourage areas is essential for effective control. Usually, a heavy initial treatment is followed by periodic follow-up treatments. Sewer shafts sprayed once with chlorpyrifos or diazinon may remain cockroach-free for nine months or more (*8*).

Insecticides

Because of the development of resistance, and for environmental reasons, the chlorinated hydrocarbons have been replaced by the biodegradable organophos-phorus and carbamate insecticides, the synthetic pyrethroids and, most recently, by insect growth regulators. Insect growth regulators are compounds that are highly toxic to insect larvae or pupae, interfering with their development into adults (see also Chapter 1, p. 134). They have a very low toxicity to non-target organisms. Their use is limited by their high cost and limited availability, but they may be of considerable value where cockroaches have developed resistance to other commonly used insecticides. Table 5.1 lists a number of these insecticides and the recommended dosages. For more information on spraying and the safe use of insecticides, see Chapters 9 and 10.

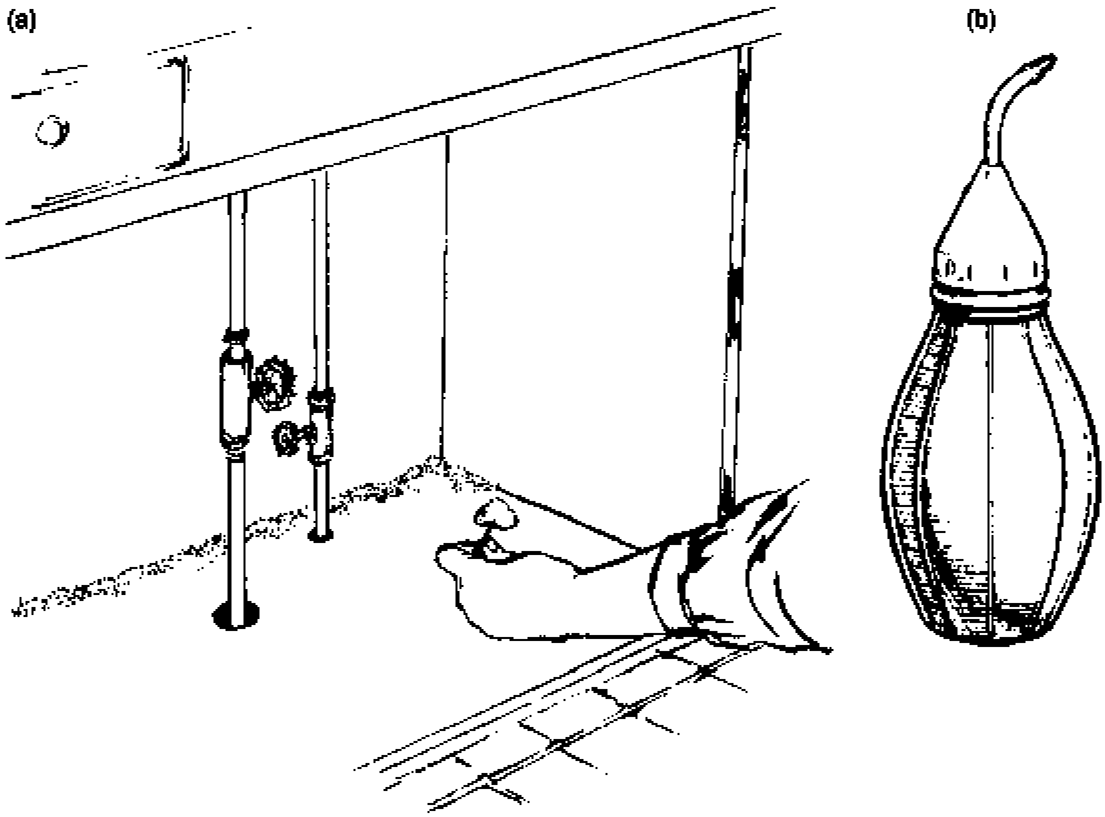


Fig. 5.8. Insecticidal dusts can be applied with (a) a spoon (© L. Robertson) or (b) a puff-duster (© WHO).

Dusts

Dry powder formulations are made by mixing insecticide powder with talcum or another inert carrier powder. They are most useful for the treatment of hollow walls, false ceilings and other cockroach hiding places that cannot easily be reached. The powders can be blown into spaces with a hand-operated puff-duster or a plunger-type duster, or even applied with a spoon (Fig. 5.8). Long, slender extension tubes can be attached to some types of duster to put the dust deep into hiding places. The dust disperses well and may penetrate deep into cracks and crevices. Heavy dust deposits may repel or drive away cockroaches and cause them to move to untreated areas or less accessible places. Dusts should not be applied to wet surfaces as this reduces their effectiveness. When used together with residual sprays, dusts should be applied only once the sprayed surfaces are dry.

Aerosols

Insecticidal aerosols are fine sprays of very small (0.1-50 mm) droplets of insecticide. Aerosols are not suitable for residual treatment but they can be used for space spraying because the droplets remain in the air for some time, killing insects by contact. Aerosol spray cans containing a residual insecticide with a knock-down insecticide (e.g. propoxur and a pyrethroid) are suitable for cockroach control and are widely available. Aerosols can penetrate into small crevices and other enclosed, inaccessible cockroach hiding places (Fig. 5.9). They usually contain pyrethrins, pyrethroids or another irritant to drive cockroaches out of their hiding places so as to shorten the time of kill. Aerosol application can cause a quick reduction in cockroach numbers but, to obtain longer-lasting control, follow-up treatment with a residual spray may be necessary (see p. 295).

Table 5.1 Insecticides commonly employed in the control of cockroaches

Insecticide	**Chemical type[a]**	**Formulation**	**Concentration**		**Safety classification by WHO[b]**
			g/l or g/kg	**%**	
Alphacypermethrin	PY	spray	0.15	0.015	MH
Bendiocarb	C	spray	2.4-4.8	10.24-0.48	MH
		dust	10	11.0	
		aerosol	7.5	10.75	
Betacyfluthrin	PY	spray	-	12.5	MH
Chlorpyrifos	OP	spray	5	10.5	MH
Cyfluthrin	PY	spray	-	15-10	MH
Cyphenothrin	PY	spray	1.25-2.5	10.125-0.25	SH
		aerosol	1-3	10.1-0.3	
Deltamethrin	PY	spray	0.025	10.0025	MH
		dust	0.5	10.05	
		aerosol	0.2	10.02	
Diazinon	OP	spray	5	10.5	MH
		dust	20	12.0	
Dichlorvos	OP	spray	5	10.5	HH
		bait	119	11.9	
Dioxacarb	C	spray	5-10	10.5-1.0	MH
Fenitrothion	OP	bait	250	25	MH
		spray	5-10	10.5-1.0	
		aerosol	1 7.5	10.75	
Flufenoxuron	IGR	bait	1 0.01	10.001	SH
Hydramethylnon	ETI	bait	-	11-2	SH
Jodfenphos	OP	spray	10	11.0	UH
Malathion	OP	spray	30	13.0	SH
		dust	50	15.0	

Permethrin	PY	spray	1 1.25-2.5	10.125-0.25	MH
		dust	1 5	10.5	
Pirimiphos methyl	OP	spray	25	12.5	SH
		dust	20	12.0	
Propetamphos[c]	OP	spray	1 5-10	10.5-1.0	HH
		dust	20	12.0	
		aerosol	20	12.0	
Propoxur	C	spray	10	11.0	MH
		bait	20	12.0	

[a] C = carbamate; OP = organophosphorus compound; PY = synthetic pyrethroid; IGR = insect growth regulator; ETI = electron transport inhibitor.

[b] Classes: HH = highly hazardous; MH = moderately hazardous; SH = slightly hazardous; UH = unlikely to present acute hazard in normal use.

[c] If applied by non-commercial operators, it should be supplied, for safety reasons, in a diluted form not exceeding 50g of active ingredient per litre.

Fig. 5.9. An aerosol spray being used to apply residual insecticide to cockroach hiding places under a kitchen sink.

Cities sometimes control cockroaches on a large scale with fogs produced by thermo-fogging machines.

Smokes

Smokes are clouds of insecticide particles produced by heat. The particle size (0.001-0.1 mm) is smaller than in aerosols. Smokes penetrate deep into hiding places and are particularly useful in basements of buildings and sewer and drainage systems.

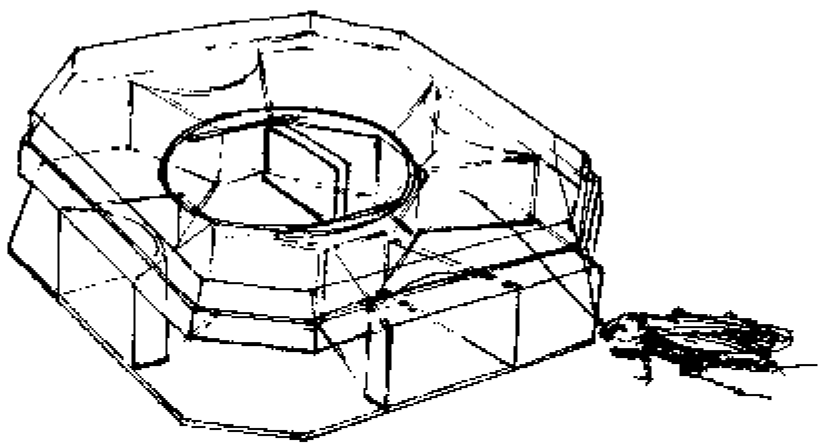
Baits and traps

Baits have been used for many years in cockroach control and are still employed in certain situations, such as offices and laboratories, particularly if there is resistance to some of the insecticides in use.

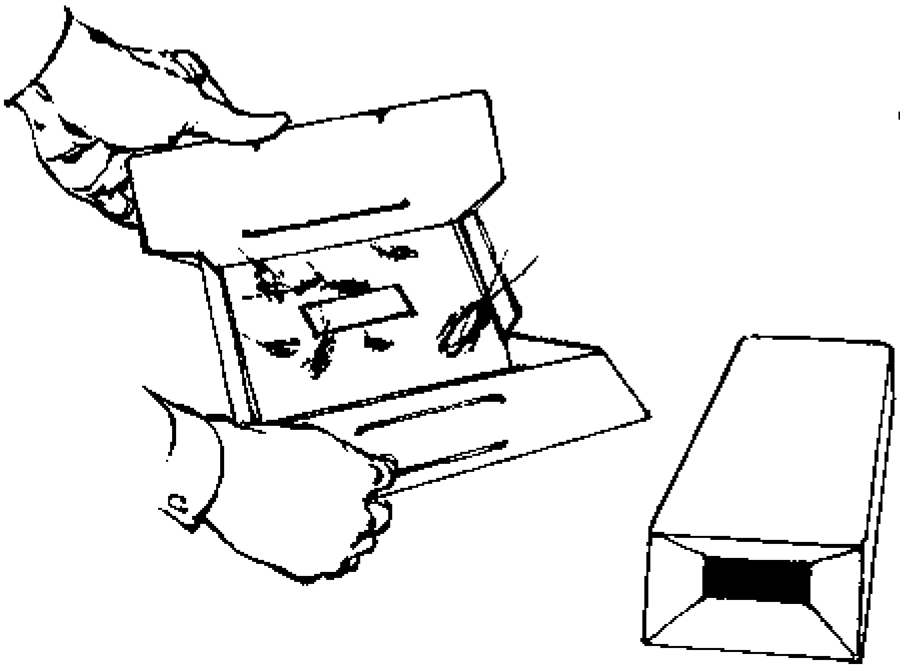
Many commercially available products work on the principle of attracting cockroaches to a specific point and then trapping or killing them there. Some substances used as attractants are various food items, pheromones and other attractive chemicals. The trapping element may be a mechanical trap or a sticky material. A simple jar trap can be constructed from an empty jar, petroleum jelly and some food: the cockroaches are attracted to the jar by bread, raisins or other food placed at the bottom, and a thin layer of petroleum jelly on the inside rim prevents the insects from escaping (Fig. 5.10).

Toxic baits are used without a trapping device. They consist of a mixture of attractive food material and an insecticide. Several types of bait are commercially available as pellets or pastes. Pellets are usually dispensed in small containers or scattered in concealed areas. Pastes can also be dispensed in small containers. Some of the newer formulations are self-drying and can be applied directly to surfaces. In some countries, dry baits are available in sealed traps which are safe to use where children or pets are present. Some food materials which may be used in baits are peanut meal, dog food and maltose.

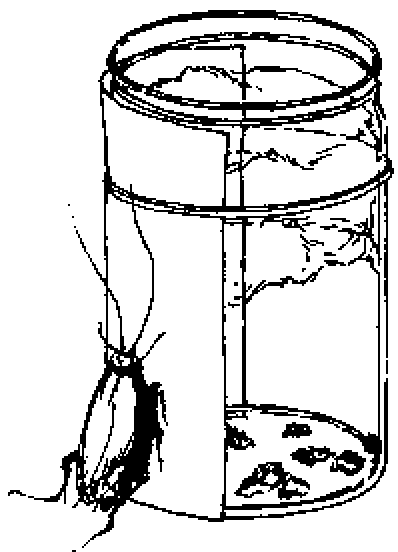
Fig. 5.10. Some types of trap.



(a) A sophisticated mechanical trap, containing attractant food.



(b) Sticky paper with trapped cockroaches: the trap contains a chemical attractant.



(c) A simple jar trap baited with raisins: a sheet of paper enables cockroaches to enter, and a thin coating of jelly prevents escape.

Application

Baits and traps are easy to use and should be placed at sites frequented by cockroaches. They are most effective in situations where there is little or no food to compete with the bait, as is the case in offices. The maintenance of environmental hygiene is especially important when baits are used alone. In heavily infested areas, baits need to be replaced frequently.

Repellents

There is growing interest in the use of repellents in the control of cockroaches. They may be of special interest for application to hiding places in shipping containers, and in cases and boxes containing drinks, food and other materials. Keeping cockroaches away from such places prevents the distribution or movement of the insects from one locality to another. Repellents can also be used in kitchen cupboards, food and beverage vending machines, and so on.

Several essential oils, such as mint oil, spearmint oil and eucalyptus oil are known to repel cockroaches, but the best results are obtained with synthetic products that are easier to standardize. For example, packing materials or interior surfaces of storerooms can be treated with appropriate dilutions of deet (*N*,*N*-diethyl-3-toluamide) or DMP (dimethyl phthalate). A deposit of 0.5 mg of deet per cm^2 repels more than 90% of *Blattella germanica* and more than 80% of *Periplaneta americana* from cardboard boxes for about a week, depending on temperature and humidity. More promising synthetic compounds, such as DEPA (*N*,*N*-diethylphenylacetamide) and DECA (diethylcyclohexylacetamide), currently being studied in India (*9*), may be commercially available in the near future.

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Chapter 6 - Houseflies

Carriers of diarrhoeal diseases and skin and eye infections

The common housefly, *Musca domestica*, lives in close association with people all over the world (Fig. 6.1). The insects feed on human foodstuffs and wastes where they can pick up and transport various disease agents. In addition to the housefly, a number of other fly species have adapted to life in human settlements, where they present similar problems. In warmer climates, the filth fly, *M. sorbens* is of particular interest in this regard. It is closely related to the housefly and considered important in the spread of eye infections. Blowflies (Calliphoridae) and other flies have been associated with the transmission of enteric infections.

Biology

Life cycle

There are four distinct stages in the life of a fly: egg, larva or maggot, pupa and adult (Fig. 6.2). Depending on the temperature, it takes from 6 to 42 days for the egg to develop into the adult fly. The length of life is usually 2-3 weeks but in cooler conditions it may be as long as three months.

Eggs are usually laid in masses on organic material such as manure and garbage. Hatching occurs within a few hours. The young larvae burrow into the breeding material; they must obtain oxygen from the atmosphere and can, therefore, survive only where sufficient fresh air is available. When the breeding medium is very wet they can live on its surface only, whereas in drier materials they may penetrate to a depth of several centimetres.

The larvae of most species are slender, white, legless maggots that develop rapidly, passing through three instars. The time required for development varies from a minimum of three days to several weeks, depending on the species as well as the temperature and type and quantity of food available. After the feeding stage is completed the larvae migrate to a drier place and burrow into the soil or hide under objects offering protection. They form a capsule-like case, the puparium, within which the transformation from larva to adult takes place. This usually takes 2-10 days, at the end of which the fly pushes open the top of the case and works its way out and up to the surface. Soon after emergence the fly spreads its wings and the body dries and hardens. The adult fly is grey, 6-9 mm long and has four dark stripes running lengthwise on the back. A few days elapse before the adult is capable of reproduction. Under natural conditions an adult female rarely lays eggs more than five times, and seldom lays more than 120-130 eggs on each occasion.

Food

Both male and female flies feed on all kinds of human food, garbage and excreta, including sweat, and on animal dung. Under natural conditions flies seek a wide variety of food substances. Because of the structure of their mouthparts, food must be either in the liquid state or readily soluble in the salivary gland secretions or in the crop. Liquid food is sucked up and solid food is wetted with saliva, to be dissolved before ingestion. Water is an essential part of a fly’s diet and flies do not ordinarily live more than 48 hours without access to it. Other common sources of food are milk, sugar, syrup, blood, meat broth and many other materials found in human settlements. The flies evidently need to feed at least two or three times a day.

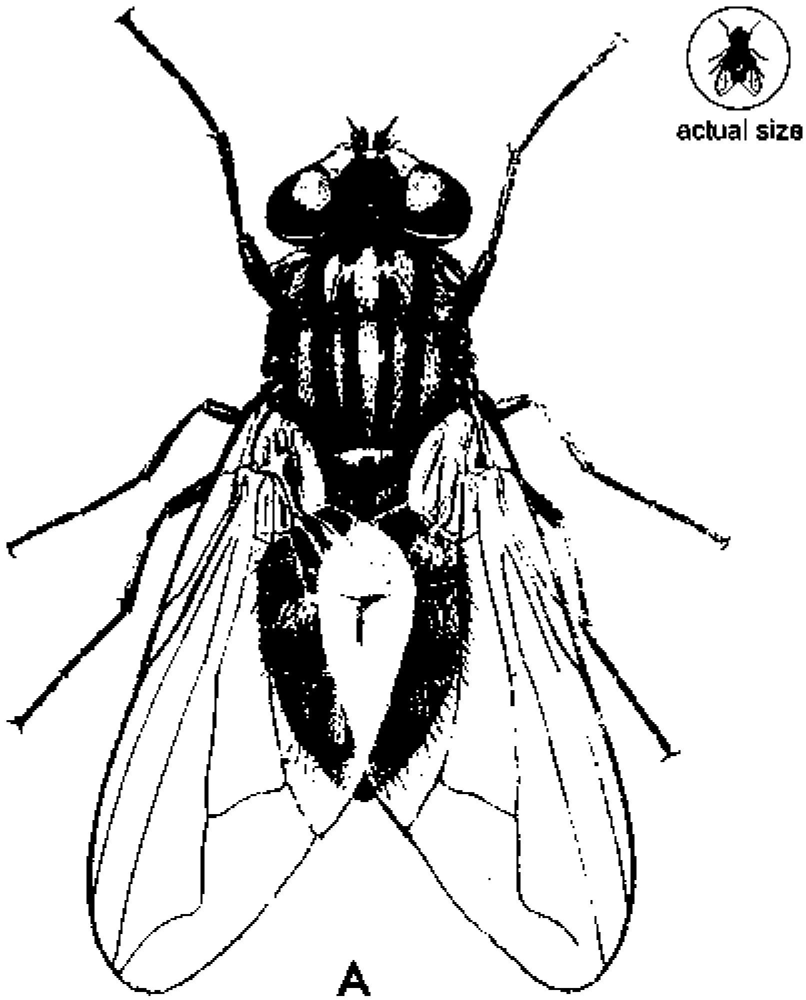


Fig. 6.1. The housefly (*Musca domestica*) (by courtesy of the Natural History Museum, London).

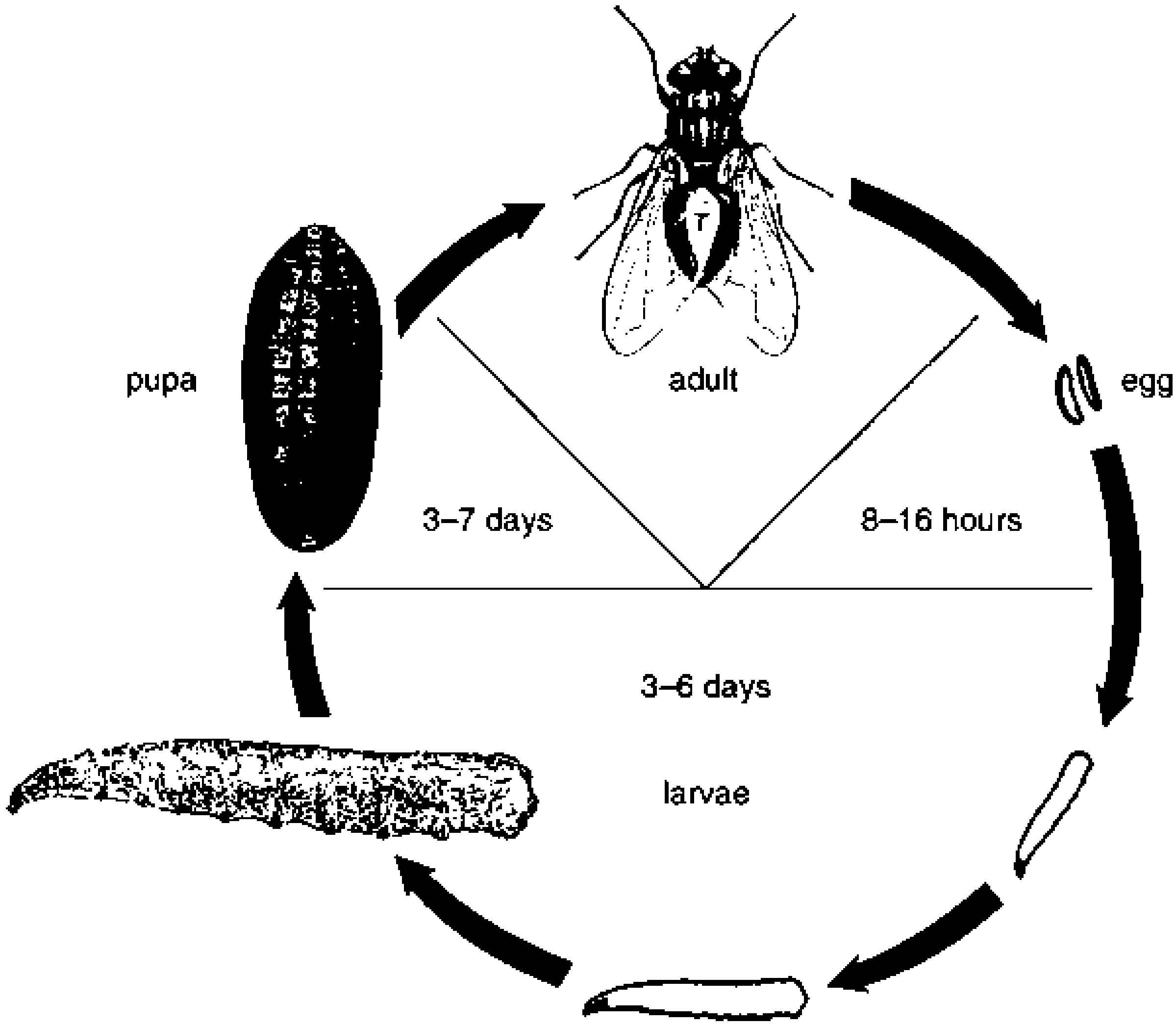


Fig. 6.2. The life cycle of the fly (© WHO).
WHO 96494

Breeding sites

Female flies deposit their eggs on decayed, fermenting or rotting organic material of either animal or vegetable origin. Unlike blowflies and fleshflies, houseflies rarely breed in meat or carrion.

Dung

Heaps of accumulated animal faeces are among the most important breeding sites for houseflies. The suitability of dung for breeding depends on its moisture (not too wet), texture (not too solid) and freshness (normally within a week after deposition).

Garbage and waste from food processing

Garbage provides the main medium for breeding (Fig. 6.3). It includes waste associated with the preparation, cooking and serving of food at home and in public places, and with the handling, storage and sale of food, including fruits and vegetables, in markets.

Organic manure

Fields that are heavily manured with organic matter such as dung, excrement, garbage and fish- meal may provide suitable breeding places for flies.

Fig. 6.3. Garbage is the main medium for fly breeding in urban areas.

Sewage

Houseflies also breed in sewage sludge and solid organic waste in open drains, cesspools (underground pools for household sewage) and cesspits.

Accumulated plant materials

Piles of decaying grass clippings, compost heaps and other accumulations of rotting vegetable matter serve as good breeding places for flies.

Ecology of adult flies

An understanding of the ecology of flies helps to explain their role as carriers of disease and allows the planning of control measures. Adult flies are mainly active during the day, when they feed and mate. At night they normally rest, although they adapt to some extent to artificial light.

Resting places

During the daytime, when not actively feeding, flies may be found resting on floors, walls, ceilings and other interior surfaces as well as outdoors on the ground, fences, walls, steps, simple pit latrines, garbage cans, clothes lines, grasses and weeds.

At night, flies are normally inactive. Their favourite resting places at this time are ceilings and other overhead structures. When temperatures remain high during the night, houseflies frequently rest out of doors on fences, clothes lines, electric wires, cords, weeds, grasses, hedges, bushes and trees. These resting places are generally near favoured daytime feeding and breeding areas and sheltered from the wind. They are usually above ground level, but rarely more than five metres high.

Fluctuations in fly numbers

Fly numbers in a given locality vary with the availability of breeding places, sunshine hours, temperature and humidity. Fly densities are highest at mean temperatures of 20-25 °C; they decrease at temperatures above and below this range and become undetectable at temperatures above 45 °C and below 10 °C. At very low temperatures, the species can stay alive in a dormant state in the adult or pupal stage.

Behaviour and distribution

During the day, flies are mainly gathered on or around feeding and breeding places, where mating and resting also take place (Fig. 6.4). Their distribution is greatly influenced by their reactions to light, temperature, humidity, and surface colour and texture. The preferred temperature for resting is between 35°C and 40 °C. Oviposition, mating, feeding and flying all stop at temperatures below 15 °C.

Flies are most active at low air humidities. At high temperatures (above 20 °C), most houseflies spend the time outdoors or in covered areas near the open air.

Fig. 6.4. Food market. During the day adult flies can be found in large numbers on food tables, garbage and the ground.

When not eating, flies rest on horizontal surfaces and on hanging wires and vertically suspended articles and ceilings indoors, especially at night. A detailed study of local resting places is essential for successful control.

Public health importance

Nuisance

In large numbers flies can be an important nuisance by disturbing people during work and at leisure. Flies soil the inside and outside of houses with their faeces. They can also have a negative psychological impact because their presence is considered a sign of unhygienic conditions.

Diseases

Flies can spread diseases because they feed freely on human food and filthy matter alike. The fly picks up disease-causing organisms while crawling and feeding. Those that stick to the outside surfaces of the fly may survive for only a few hours, but those that are ingested with the food may survive in the fly's crop or gut for several days. Transmission takes place when the fly makes contact with people or their food (Fig. 6.5). Most of the diseases can also be contracted more directly through contaminated food, water, air, hands and person-to-person contact. This reduces the relative importance of flies as carriers of disease.

Fig. 6.5. Humans can be infected by eating food contaminated by flies.

Fig. 6.6. People who keep cattle are sometimes surrounded by large numbers of filth flies (*Musca sorbens*), important vectors of certain eye infections.

The diseases that flies can transmit include enteric infections (such as dysentery, diarrhoea, typhoid, cholera and certain helminth infections), eye infections (such as trachoma and epidemic conjunctivitis) (Fig. 6.6), poliomyelitis and certain skin infections (such as yaws, cutaneous diphtheria, some mycoses and leprosy).

Control measures

Flies can be killed directly by insecticides or physical means such as traps, sticky tapes, fly swats and electrocuting grids. However, they should preferably be controlled by improving environmental sanitation and hygiene. This approach provides longer-lasting results, is more cost-effective and usually has other benefits.

Improvement of environmental sanitation and hygiene

Four strategies can be employed:

- reduction or elimination of fly breeding sites;
- reduction of sources that attract flies from other areas;
- prevention of contact between flies and disease-causing germs;
- protection of food, eating utensils and people from contact with flies.

Reduction or elimination of fly breeding sites

Animal sheds, stables, pens and feed lots

Solid concrete floors with drains should be constructed; dung should be cleaned out and floors should be flushed daily.

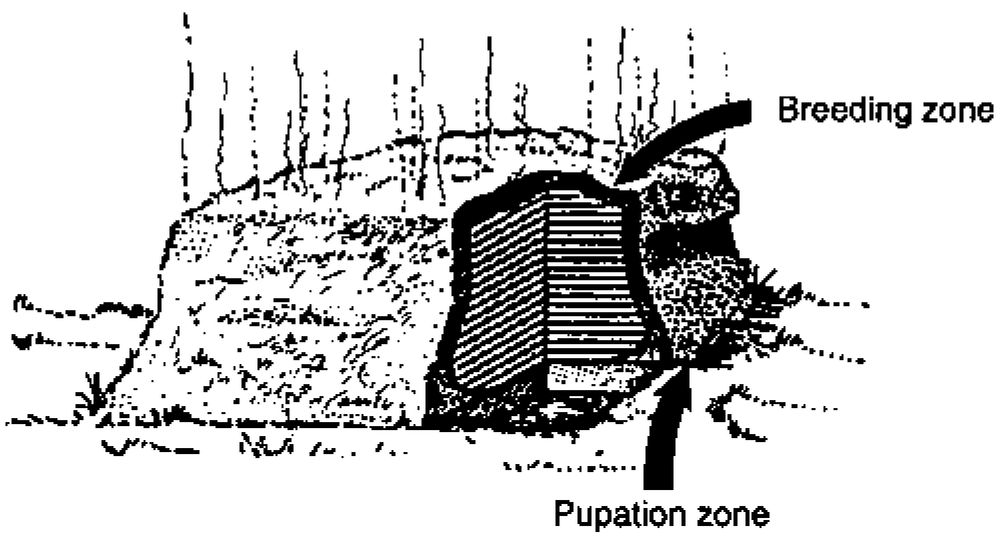
Poultry houses

Where birds are kept in cages and dung accumulates below them, fans should be used to dry it; leaking water pipes should be repaired, dung should be removed and the floors should be flushed at frequent intervals.

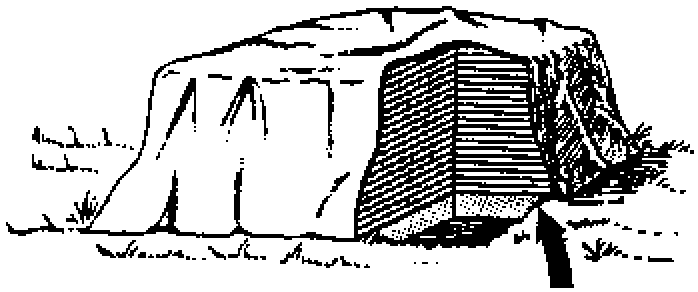
Dung heaps

Dung should be stacked to reduce the surface area and the zone in which the temperature is suitable for fly breeding. It should be covered with plastic sheets or e.g. a plastic sheet, over the dung; the sheet reduces heat loss and the surface layers become too hot for breeding (© WHO). other fly-proof material. This prevents egg-laying and kills larvae and pupae as the heat produced in the composting process can no longer escape (Fig. 6.7). It is preferable to stack the dung on a concrete base, surrounded by gutters to prevent the migration of larvae to pupate in soil around the heap. In hot climates, dung may be spread on the ground and dried before the flies have time to develop.

Fig. 6.7. Fly breeding in dung heaps can be prevented by placing a light cover,



(a)



(b)

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Human excreta

Breeding in open pit latrines can be prevented by the installation of slabs with a water seal and a fly screen over the vent pipe. If a water seal is not feasible, a tightly fitting lid may be placed over the drop hole. Installing a ventilated pit latrine can also reduce fly breeding (see Chapter 1 for more information).

Defecation in the field, other than in latrines and toilets, may provide breeding places for filth flies (*Musca sorbens*). This is a common problem where large groups of people, e.g. refugees, stay together in temporary camps. Installation of proper latrines should be given priority. In the absence of proper facilities, people could be asked to defecate in a special field at least 500 m downwind of the nearest habitation or food store and at least 30 m from a water supply. This reduces the numbers of flies in the camp and makes it easier to remove exposed faeces. Covering the faeces with a thin layer of soil may increase breeding since the faeces are then likely to dry out more slowly.

Garbage and other organic refuse

This breeding medium can be eliminated by proper collection, storage, transportation and disposal (Fig. 6.8). In the absence of a system for collection and transportation, garbage can be burnt or disposed of in a specially dug pit. At least once a week the garbage in the pit has to be covered with a fresh layer of soil to stop breeding by flies.

Flies are likely to breed in garbage containers even if they are tightly closed. In warm climates the larvae may leave the containers for pupation after only 3-4 days. In such places, garbage has to be collected at least twice a week. In temperate climates once a week is sufficient. When emptying a container it is important to remove any residue left in the bottom.

Fig. 6.8. Good garbage containers with tightly fitting lids may help to reduce fly breeding in towns.

WHO 96500

In most countries, garbage is transported to refuse dumps, where, to reduce breeding, it is necessary to compact the refuse and cover it daily with a solid layer of soil (15-30 cm). Such dumps should be at least several kilometres away from residential areas.

As discussed in Chapter 1, refuse can be used for filling mosquito breeding places in borrow-pits, marshy areas and other low-lying sites. If properly covered with soil, the sites are called sanitary landfills (Fig. 6.9).

In some cities, large quantities of refuse are burned in incinerators. In dry areas, simple small incinerators can be installed.

Soil impregnated with organic matter

Accumulations of sludge and solid organic waste in open sewage drains, cesspools and seepage pits have to be removed (Fig. 6.10). Drains can be flushed out afterwards. Fly breeding can be reduced by covering the drains but, as discussed in Chapter 1, this may cause problems when drains are not maintained properly. Outlets of wastewater on soil should be eliminated.

Special precautions should be taken in abattoirs and places where fish is handled and sold. If possible, concrete floors should be installed with drains to facilitate cleaning.

In places where manure is used to fertilize fields, heavy applications in lumps should be avoided.

Reduction of sources that attract flies from other areas

Flies are attracted by the odour emanating from breeding sites. In addition they are attracted by products such as fish-meal and bone-meal, molasses and malt from breweries, milk, and sweet-smelling fruit, especially mangoes.

Attraction to waste can be prevented by cleanliness, the removal of waste, and its storage under cover. Industries using attractive products can install special exhausts for odours.

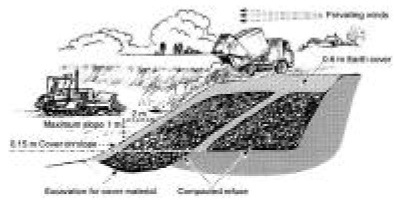

Fig. 6.9. Sanitary landfill (1).

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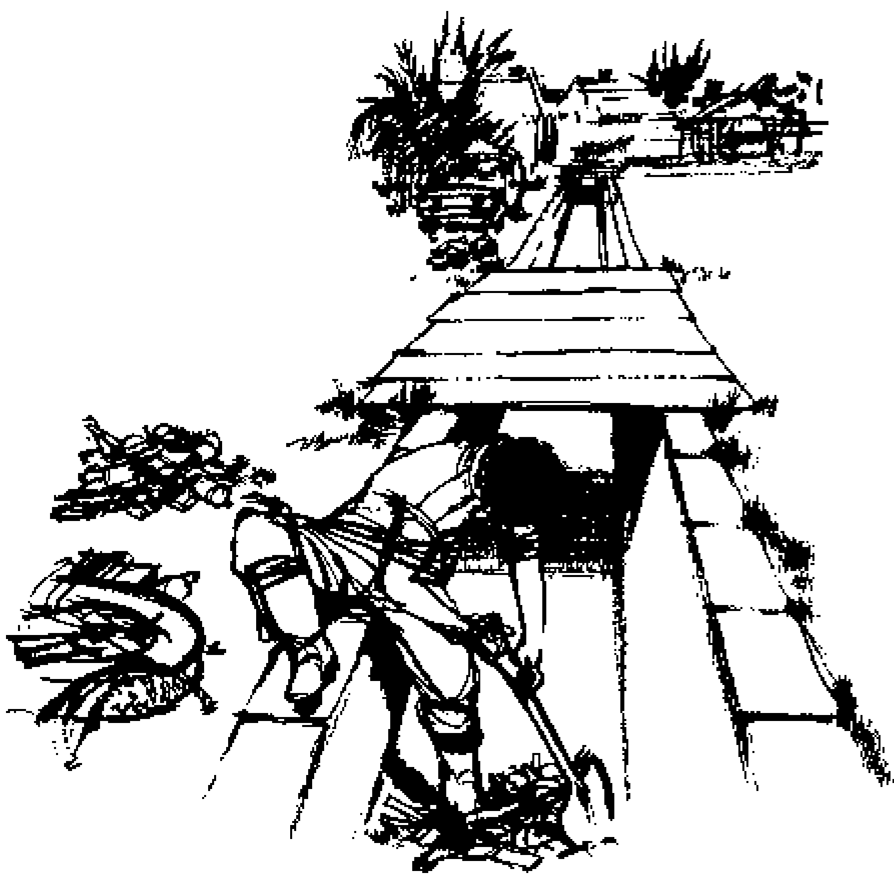

Fig. 6.10. Regular cleaning of drains is needed to avoid fly breeding in accumulations of garbage.

Prevention of contact between flies and disease-causing germs

The sources of germs include human and animal excrement, garbage, sewage, infected eyes, and open sores and wounds. Measures to eliminate fly breeding also reduce contact between flies and germs. The most important are:

- the installation and use of proper latrines and toilets where flies cannot make contact with faeces;

- the prevention of contact between flies and sick people, their excreta, soiled baby nappies, open sores, and infected eyes;

- the prevention of access of flies to slaughter offal and dead animals.

Protection of food, eating utensils and people from contact with flies

Food and utensils can be placed in fly-proof containers, cupboards, wrapping materials, etc. Nets and screens can be used on windows and other openings. Doors can be made self-closing. Doorways can be provided with anti-fly curtains, consisting of strings of beads or plastic strips which touch each other and prevent flies from passing through (Fig. 6.11). Nets can be placed over babies to protect them from flies, mosquitos and other insects, and can also be used to cover food or utensils (Fig. 6.12). Electric fans can create an air barrier across entrances or corridors that have to be kept open.

The screening of buildings is the most important method but it may cause inconvenience because of reduced ventilation and light. Mesh with openings of 2-3 mm is sufficient unless it is desired to exclude mosquitos also, in which case the openings should be 1.5 mm or less (see Chapter 1). Plastic-coated material is preferable to metal because the latter may corrode.

Flies that enter screened rooms can be killed with traps, sticky tapes or space sprays delivered from an aerosol spray can.

Fig. 6.11. Door screens made of strings of beads can serve as a barrier against flies and other insects.

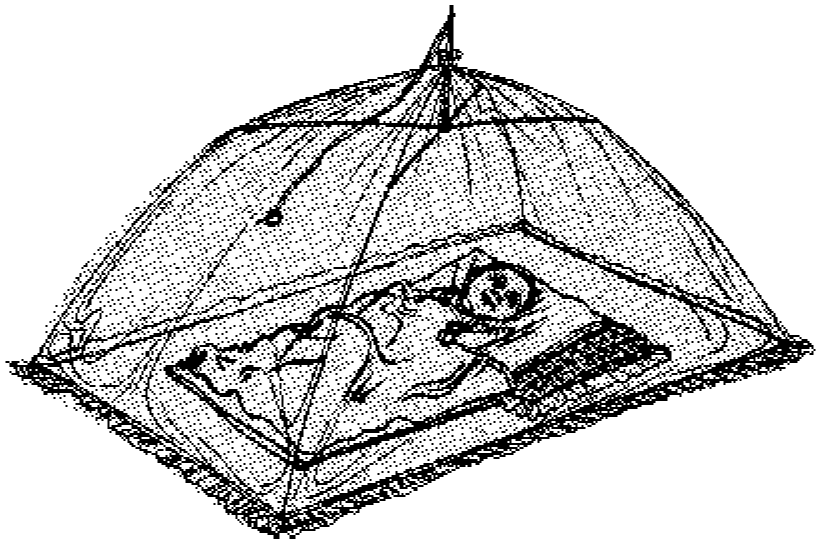

Fig. 6.12. Self-supporting fly nets can be used to protect babies from flies.

Methods of killing flies directly

The methods that can be used to kill flies directly can be classified as physical or chemical. They are presented below roughly in order of increasing complexity to the user.

Physical methods

Physical control methods are easy to use and avoid the problem of insecticide resistance, but they are not very effective when fly densities are high. They are particularly suitable for small-scale use in hospitals, offices, hotels, supermarkets and other shops selling meat, vegetables and fruits.

Fly traps

Large numbers of flies can be caught with fly traps. An attractive breeding and feeding place is provided in a darkened container. When they try to leave, the flies are caught in a sunlit gauze trap covering the opening of the container. This method is suitable only for use out of doors.

One model consists of a plastic container or tin for the bait, a wooden or plastic cover with a small opening, and a gauze cage resting on the cover. A space of 0.5 cm between the cage and the cover allows flies to crawl to the opening (Fig. 6.13).

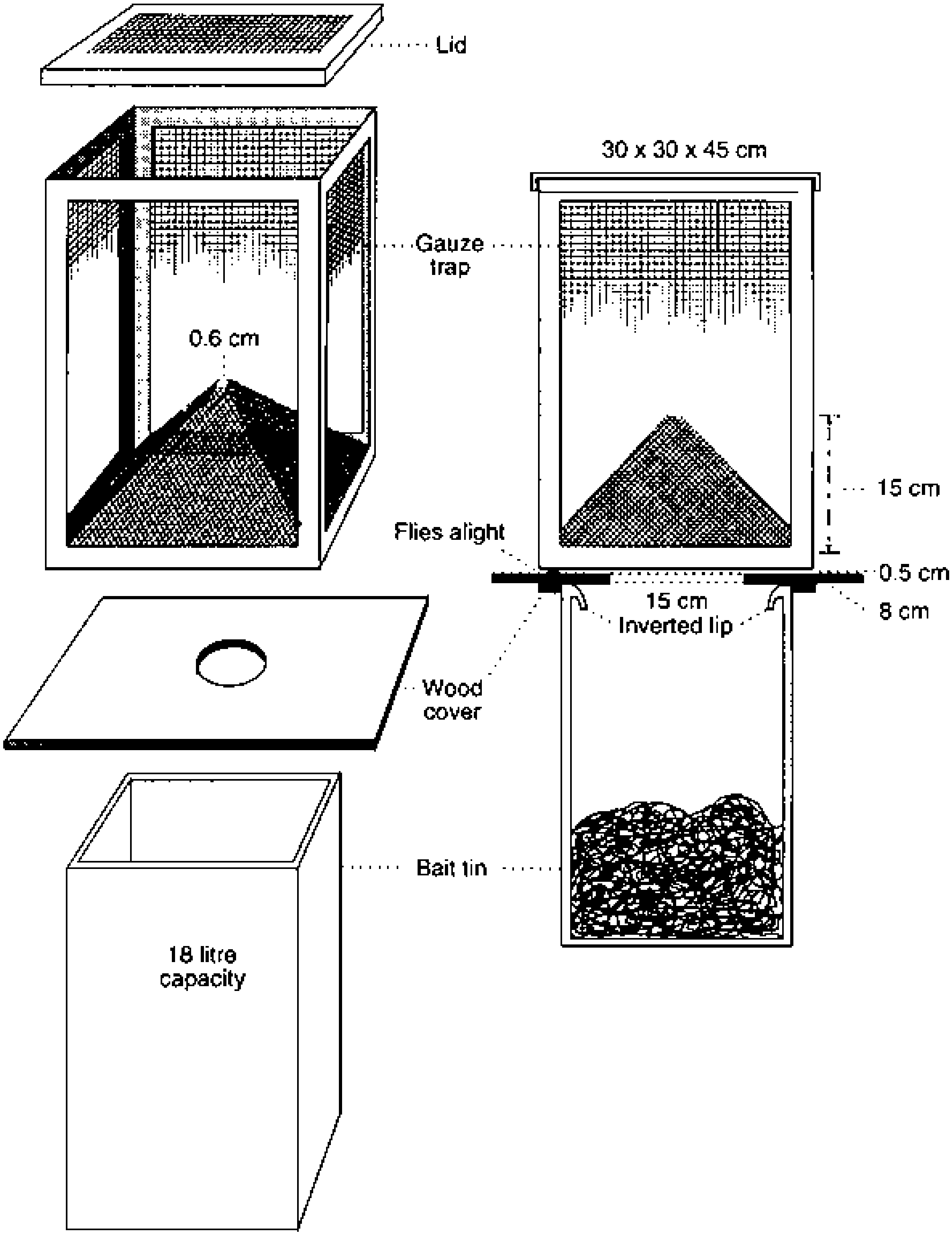

Fig. 6.13. Components of a fly trap (© WHO).

WHO 96505

The container should be half-filled with bait, which should be loose in texture and moist. There should be no water lying at the bottom. Decomposing moist waste from kitchens is suitable, such as green vegetables and cereals and overripe fruits. Chunks of decomposing meat or fish can be added. Where evaporation is rapid the bait has to be moistened on alternate days. Other suitable baits are described on p. 316.

After seven days the bait will contain a large number of maggots and needs to be destroyed and replaced. Flies entering the cage soon die and gradually fill it until the apex is reached and the cage has to be emptied. The trap should be placed in the open air in bright sunlight, away from shadows of trees.

Sticky tapes

Commercially available sticky tapes, suspended from ceilings, attract flies because of their sugar content. Flies landing on the tapes are trapped in a glue. The tapes last for several weeks if not fully covered by dust or trapped flies.

Light trap with electrocutor

Flies attracted to the light are killed on contact with an electrocuting grid that covers it (Fig. 6.14). Blue and ultraviolet light attracts blowflies but is not very effective against houseflies. The method should be tested under local conditions before an investment is made. It is sometimes used in hospital kitchens and restaurants.

Chemical methods

Control with insecticides should be undertaken only for a short period when absolutely necessary because flies develop resistance very rapidly. The application of effective insecticides can temporarily lead to very quick control, which is essential during outbreaks of cholera, dysentery or trachoma.

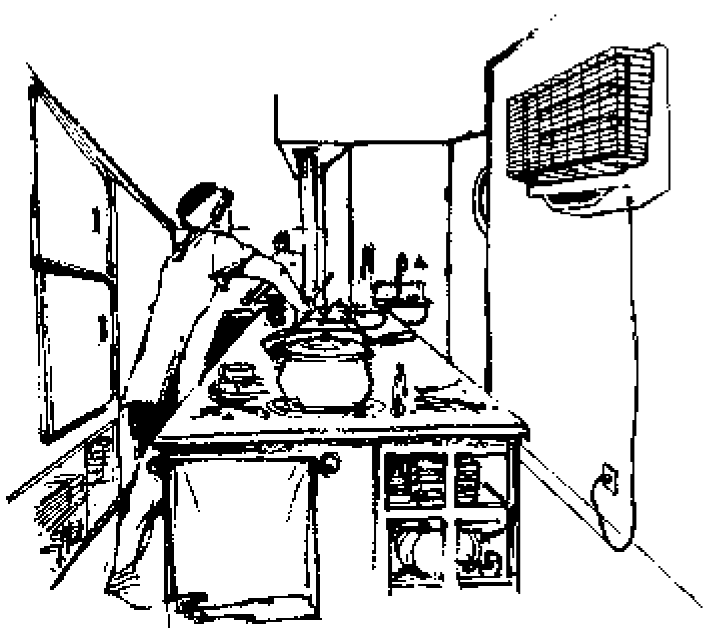

Fig. 6.14. Light trap with electrocutor.

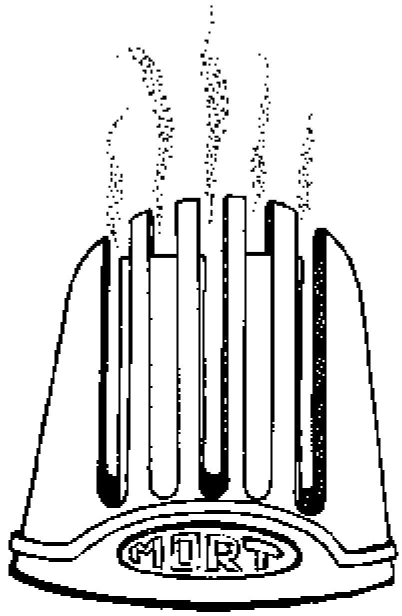

Fig. 6.15. A dichlorvos vapour dispenser.

Dichlorvos vaporizer

Insecticide vaporizers such as strips of absorbent material impregnated with dichlorvos are commercially available (Fig. 6.15). They release dichlorvos slowly over a period of up to three months provided that ventilation is limited. Most strips are made to treat rooms of 15-30 m^3.

This method is effective only in places with little ventilation. There is a possible danger of some toxic effects in humans and the method should not be used in rooms where infants or old people are sleeping. For more information, see Chapter 1, p. 68.

Introduction of toxic materials to resting sites

The idea of providing toxic resting sites for flies is based on the observation that houseflies prefer to rest at night on edges, strings, wires, ceilings and so on. Materials that can be impregnated with insecticide include bednets, curtains, cotton cords, cloth or gauze bands and strong paper strips. The strips can be effective for many weeks in both tropical and temperate areas. This method is cheap, has a long residual effect and is less likely to provoke insecticide resistance than are residual sprays. However, it does not work in rooms with an air draught under the ceiling, which is the case in many ventilated rooms and stables. Fly numbers are initially reduced rather slowly and other chemical methods may be more effective in giving immediate results.

Application

The materials are dipped in a diluted emulsion of insecticide, possibly with some sugar, glycerol or other attractant and glue or oil for making a durable film. After dipping, the liquid is allowed to drip off and the strips to dry. An old method makes use of bunches of twigs soaked in a toxic solution.

In the 1950s, a cheap but very toxic insecticide, parathion, was used commercially to treat bands or cords. Safer for humans and therefore preferred today are organophosphorus compounds such as diazinon, fenchlorphos, malathion, fenthion, dimethoate and trichlorfon; carbamates such as propoxur and dimetilan; and pyrethroids such as cypermethrin, deltamethrin, permethrin and cyfluthrin.

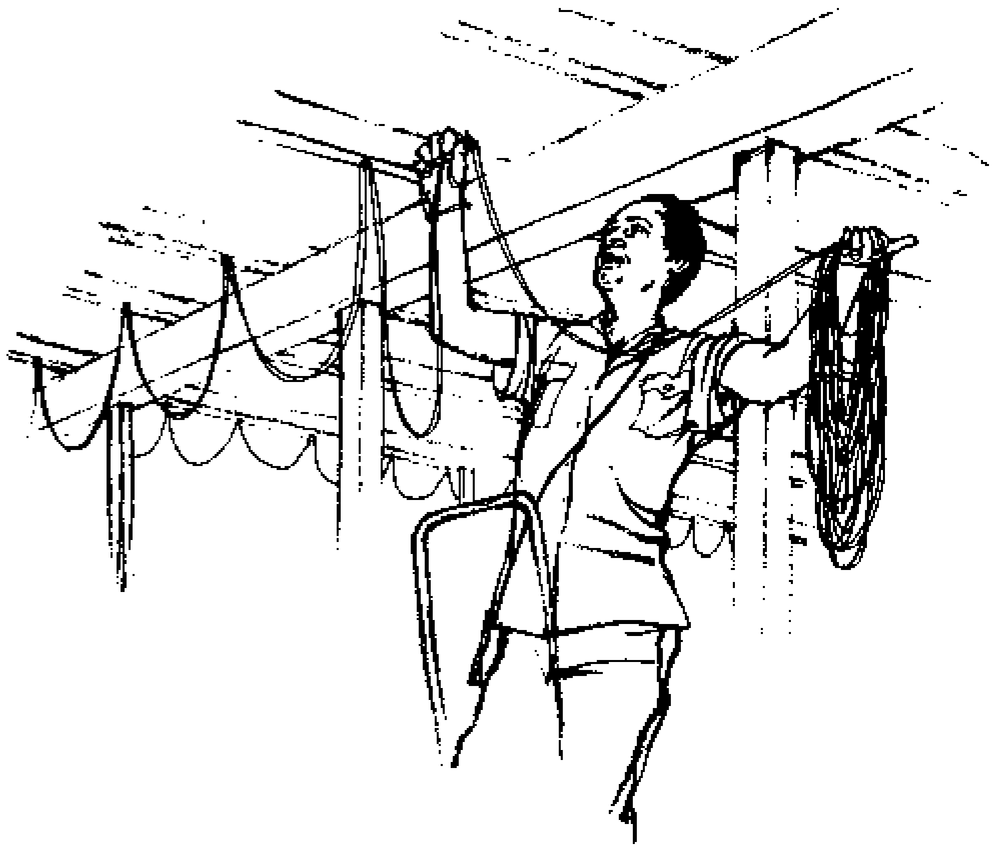

Fig. 6.16. Strips or cords of cotton, cloth or gauze impregnated with a long-lasting insecticide can easily be suspended from ceilings.

When preparing the materials it should be borne in mind that high concentrations of insecticide may be repellent or irritant to flies. Lower concentrations may therefore be more effective. The attractance or repellency of several dosages can be tested under field conditions. A solution strength of 1-10% usually gives good results with organophosphorus and carbamate insecticides.

The impregnated materials are suspended under the ceiling or other fly-infected place at the rate of about 1 metre per square metre of floor area. Vertical parts or loops are more attractive to flies than horizontal ones, and red or dark colours are better than light ones. The materials can be attached by stapling and pinning or can be suspended from a horizontal line stretched along the ceiling (Fig. 6.16).

The cords or bands can also be stretched on frames which can then be moved as required. The strips may be used in animal sheds, poultry farms, markets, shops, restaurants and any other fly-infested area.

Attraction of flies with toxic baits (Table 6.1)

Traditional toxic baits made use of sugar and water or other fly-attracting liquids containing strong poisons such as sodium arsenite. Milk or sweet liquids with 1-2% formaldehyde can still be recommended for killing flies. Improvements became possible with the development of organophosphorus and carbamate compounds that are highly toxic to flies but relatively safe to humans and other mammals.

Table 6.1 Insecticides used in toxic baits for fly control

Insecticide	Dry scatter	Liquid sprinkle	Liquid dispenser	Viscous paint-on
Organophosphorus compounds				
dichlorvos[a]	+[b]	+ +[b]	+ +	
dimethoate[a]		+	+ +	
trichlorfon[a]	+ +	+ +	+ +	+ +
azamethiphos	+			+ +
diazinon	+ +	+		+
fenchlorvos	+	+		+
malathion	+	+		+
naled	+	+		+
propetamphos				+ +
Carbamates				
bendiocarb	+ +	+		
dimetilan[a]		+	+ +	+
methomyl[c]				+ +
propoxur	+ +	+		
formaldehyde[a]			+	

[a] Aqueous suspension.

[b] + or + + indicates insecticides that are most suitable or have been most widely used for the particular type of application.

[c] Can also be used in the form of granules stuck on strips or boards.

The power of a bait depends on (a) the natural attractants to which the flies are adapted and (b) the degree of competition from other attractants (food). As a rule, baits do not attract flies at a distance. However, special attractants, other than sugar, may greatly increase the effect of baits to a radius of a few metres. These attractants include fermented yeast or animal protein (e.g. whole egg), ammonium carbonate, syrups and malt. A commercially available synthetic fly attractant, SFA, has proved to be very effective in poultry farms in certain areas. It consists of 88% commercial fish-meal, 5% ammonium sulfate, 5% trimethylamine hydrochloride, 1% linoleic acid and 1% indole. The attractants are slowly released when the bait is moistened. Another commercially available attractant is the fly pheromone muscalure which may attract flies up to three weeks after application.

Advantages

The various types of bait are cheap and easy to use. The control of flies is effective in places with moderate availability of fly breeding sites. The scattering or sprinkling of certain types of bait can cause marked reductions in fly densities within a few hours. Such applications have to be repeated up to six times a week for good control. Liquid bait dispensers and stations (trays) for dry baits may continue to be effective for a week or two. The paint-on bait is the most convenient: it can be applied easily on both horizontal and vertical fly-resting surfaces and can have a long residual effect. Flies are less likely to develop resistance to toxic baits than to residual sprays. Even flies that have developed resistance to an insecticide applied on a surface may still be killed by it in a bait formulation.

Disadvantages

Baits that are sprinkled or scattered require frequent application. Liquid baits must be placed out of reach of children and animals.

Types of bait

Dry scatter baits

These contain 0.1-2% of insecticide in a carrier, which may be plain granular sugar or sugar plus sand, ground corncobs, oyster shells, etc. Another attractant may be added. The bait should be scattered in thin layers of 60-250g per 100 m^2 on resting places such as floors. It can also be placed in special bait stations: trays or containers made of metal, wood, cardboard, etc. It is most effective if there are suitable surfaces where it can be applied.

Liquid sprinkle baits

These contain insecticide (0.1-0.2%) and sugar or other sweetening agents (e.g. 10%) in water. The liquid is applied by a sprinkling can or a sprayer to floors in places where there are no children or animals, as well as to other suitable horizontal or vertical surfaces, out of reach of animals and children.

Liquid bait dispensers

These hold formulations similar to the liquid sprinkle baits and consist of a container, inverted jar or bottle feeding trough, and a sponge or wick with the liquid (Fig. 6.17). Alternatively, mats or balls of absorbent material may be impregnated with insecticide and moistened for use.

Viscous paint-on baits

These are composed of an insecticide (2-6%), a binder and sugar (or just insecticide in syrup or molasses) to form a paint that can be applied with a brush to partitions, walls, posts, window areas and ceilings or to strips, plates, etc., which are suspended or otherwise fastened where there are concentrations of flies (Fig. 6.18). The bait sticks to the surface and may be active for weeks or months. Trichlorfon is a commonly used insecticide for this type of application. Flies that are not killed on contact with the treated surface may be killed through feeding on the bait.

Treatment of resting sites with residual insecticides

Surfaces on which flies rest can be sprayed with a long-lasting insecticide (see Chapter 9). This method has both an immediate and a long-term effect. Depending on the insecticide, the wall surface material, temperature, humidity, exposure to sunlight and the level of resistance in the flies, residual effectiveness can last from several days to a period of weeks. It is important to know where the flies spend most of their time at night. Only surfaces that have been observed to be used as resting sites should be sprayed. Residual spraying is mainly carried out in animal units on farms.

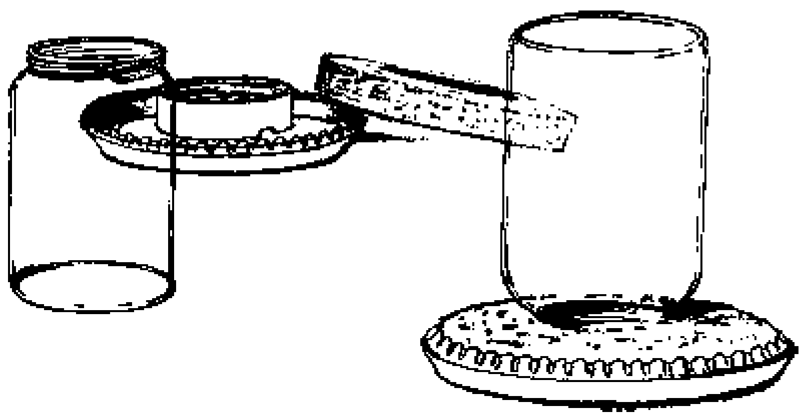

Fig. 6.17. A liquid bait device in which a sponge is kept wet by an inverted, partially filled jar.

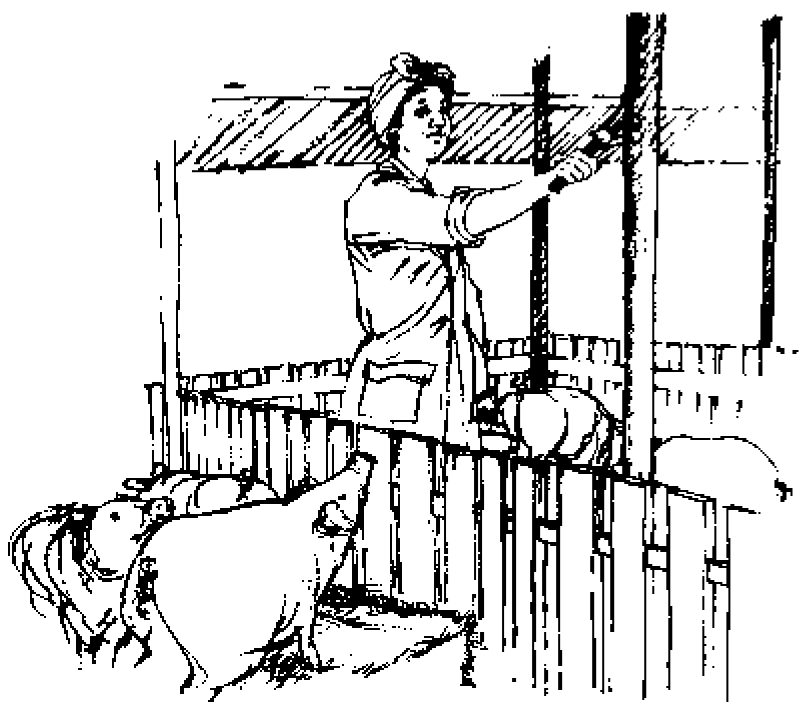

Fig. 6.18. Painting of toxic bait on places where flies often rest.

Disadvantages

The selection of an insecticide is difficult because the results given by a particular compound are likely to be good in one area and disappointing in another. The risk of resistance developing in flies is greater with residual sprays than with other chemical treatments used against adult flies.

Insecticides

Table 6.2 indicates a number of insecticides and recommended application rates for residual spraying. Prior to selection it is best to consult an expert in pest control.

Applications are made with hand-operated sprayers (Chapter 9) or power-operated sprayers at low pressure to avoid the insecticide particles drifting away.

Space-spraying

Flies can be quickly knocked down and killed by mists or aerosols of insecticide solutions or emulsions. The treatment is carried out by spraying with pressurized aerosol spray cans, hand-operated sprayers or small portable power-operated sprayers. The principle is to fill a space with a mist of small droplets that are picked up by the insects when they fly.

Table 6.2 Organophosphorus and pyrethroid insecticides used for residual treatment in fly control

Insecticide	***Dosage (g/m^2) of active ingredient***	***Remarks***
Organophosphorus compounds[a]		
azamethiphos	1.0-2.0	Mainly sold as a sugar bait.
bromophos	1.0-2.0	Low level of resistance in most places.
diazinon	0.4-1.0	
dimethoate	0.25-1.0	
chlorfenvinphos	0.4	Resistance problems in most areas.
fenchlorvos	1.0-2.0	
fenitrothion	1.0-2.0	
jodfenphos	1.0-2.0	
malathion	1.0-2.0	
pirimiphos methyl	1.0-2.0	Low level of resistance in most places. Mainly used as sugar bait formulation.
propetamphos	0.25-1.0	
trichlorfon	1.0-2.0	
Pyrethroids		
alphacypermethrin	0.02	In Canada and some parts of Europe resistance develops quickly.
cyfluthrin	0.03	
cypermethrin	0.025-0.1	

deltamethrin	0.01-0.15	
fenvalerate	1.0	
permethrin	0.025-0.1	

[a] For most of the organophosphorus compounds there are restrictions in some countries on their use in dairies, food-processing plants or other places where food is exposed, and several of these compounds are also restricted as regards exposure to chickens, dairy cows and other animals present during spraying.

Compared with residual spraying of resting surfaces, space-spraying has an immediate effect but it is short-lasting. The risk of the development of insecticide resistance is less. The method can be used indoors, outdoors and for direct spraying of aggregations of flies.

Indoor space treatments

In animal sheds, space sprays are mainly used as a supplement to residual treatments or toxic baits, but on farms where the latter treatments fail (e.g. because of resistance), frequent space-spraying may be used as a primary means of chemical control. The insecticide chosen should be safe for use with domestic animals. The treatments should be done when as many flies as possible are indoors, e.g. in the evenings.

Advantages: indoor space sprays are useful for achieving quick reductions in fly densities in houses, kitchens, restaurants, shops, animal sheds, etc. (Fig. 6.19).

Disadvantages: space sprays should not be used in kitchens or restaurants when meals are being prepared or served; the effect is limited and such sprays are mainly suitable when used as an additional method.

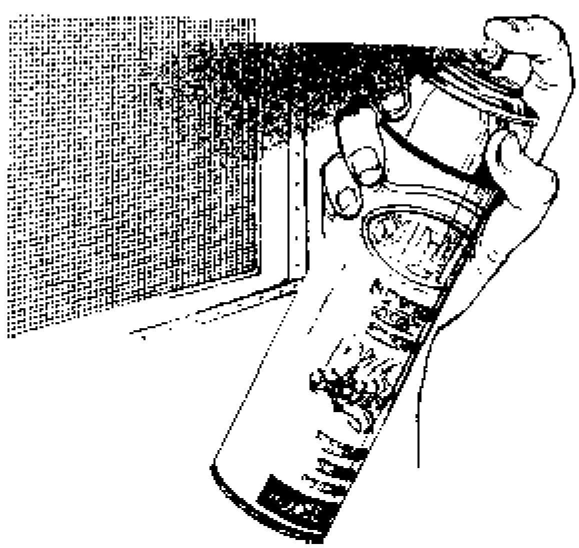

Fig. 6.19. Aerosol spray cans are widely available and are effective in killing houseflies in confined spaces.

Outdoor space treatments

Such treatments are used for quick temporary control of flies, e.g. on refuse dumps where adequate cover by soil is not possible, in recreational areas, markets and food industries, or for area control in cities and towns, especially in emergencies.

As a rule the method has only a temporary effect and it kills only flies that are exposed outdoors. Flies indoors or resting in sheltered locations may survive; those emerging from breeding sites are not controlled. Space treatments should be applied when fly densities are at a peak, for example in the morning. Daily treatments over a period of, say, two weeks may reduce the density to a level where further control can be obtained by treatments at longer intervals, e.g. 1-2 weeks.

Advantage: fly densities are reduced quickly.

Disadvantages: costs can be high because applications may have to be repeated; the method is not very successful where fly breeding sources are abundant; effectiveness depends on air currents during spraying.

Application involves mist spraying, fogging or ultra-low-volume spraying. This is done by power-operated equipment from the ground or the air. Mistblowers are most practical because they are less dependent on air currents to distribute the insecticide. Insecticides and effective dosages for outdoor space-spraying are indicated in Table 6.3.

Direct spraying of fly aggregations

Concentrations of flies on garbage can be sprayed directly with a hand- or power-operated sprayer, delivering a relatively wet spray that kills flies hit directly and leaves a toxic residue that kills those crawling over treated surfaces later in the day. These treatments may also kill larvae.

A range of organophosphorus compounds can be used in kerosene solution or aqueous emulsion at concentrations of 1-2%.

Treatment of breeding sites with larvicides

Chemical substances that kill larvae are mainly used on dung on farms. An important advantage is that control at this stage tackles the problem at its base. However, there are several drawbacks: because the dung is continuously accumulating and changing, larvicides have to be applied frequently to ensure good penetration and distribution. Another problem is that larvicides often kill the natural enemies of the flies, such as beetles, mites and earwigs. The use of larvicides may favour the development of resistance; the choice of compound should therefore be made carefully.

Table 6.3 Dosages effective in outdoor space treatments for fly control[a]

Insecticide	Dosage(g/ha) of active ingredient
Organophosphorus compounds	
azamethiphos	50-200
diazinon	340

dichlorvos	340
dimethoate	220
fenchlorvos	450
jodfenphos	350
malathion	670
naled	220
pirimiphos methyl	250
Pyrethroids	
bioresmethrin[b]	5-10
cyfluthrin	2
deltamethrin	0.5-1.0
phenothrin[b]	5-10
permethrin[b]	5-10
pyrethrins[b]	20
resmethrin[b]	20

[a] In areas where flies are not resistant to the insecticide.

[b] May be combined with other pyrethroids giving quick knockdown or with a synergist such as piperonyl butoxide (5-10g/ha).

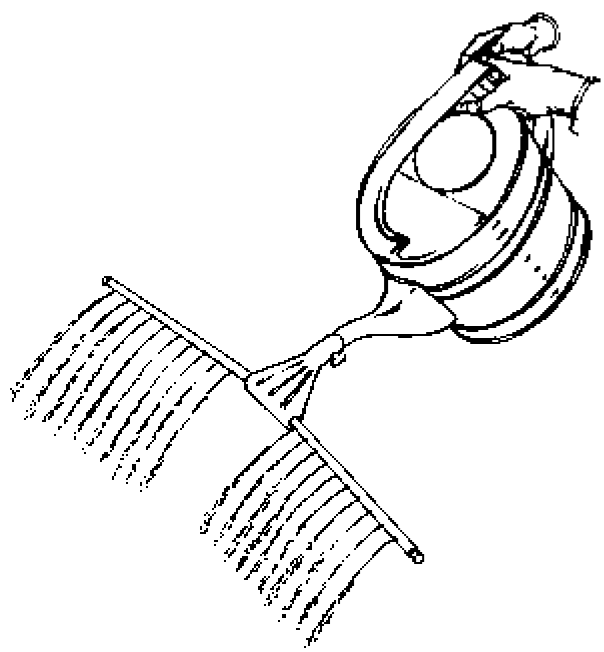

Fig. 6.20. Application of larvicide with a watering can.

Provided there is no resistance, effective compounds and their recommended rates are as follows:

- the organophosphorus compounds dichlorvos and diazinon at 0.3-1.0g/m^2, and trichlorfon, dimethoate, fenchlorvos, tetrachlorvinphos, bromophos, fenitrothion and fenthion at 1-2g/m^2;

- the insect growth regulators diflubenzuron, cyromazine and triflumuron at 0.5-1.0g/m^2 and pyriproxyfen at 0.1g/m^2; this group prevents larval development for 2-3 weeks.

Larvicides are applied with a sprayer or a watering can as emulsions, suspensions or solutions (Fig. 6.20). The dosage has to be sufficient to wet the upper 10-15 cm of the substrate, i.e. 0.5-5 litres/m^2.

Reference

1. Keiding J. *The housefly-biology and control. Training and information guide (advanced level)*. Geneva, World Health Organization, 1986 (unpublished document WHO/VBC/86.937; available on request from Division of Control of Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland).

Selected further reading

The housefly. Training and information guide (intermediate level). Geneva, World Health Organization, 1991 (unpublished document WHO/VBC/90.987; available on request from Division of Control of Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland).

Chapter 7 - Cyclops

Intermediate hosts of guinea worm

Cyclops are tiny crustaceans of the family Cyclopidae, also called water fleas. They are usually found in stagnant bodies of fresh water such as wells and ponds in poor agricultural communities in rural or periurban areas. In sub-Saharan Africa, India and Yemen they are the intermediate hosts of guinea worm, *Dracunculus medinensis*, a parasite that causes guinea-worm disease or dracunculiasis. The disease is transmitted to humans when they drink water containing infected cyclops.

Guinea-worm disease is rarely fatal but is severely debilitating. The lower limbs are most commonly affected but the worms, which are up to a metre in length, can emerge from any part of the body. There are no drugs to treat the disease but highly effective and simple preventive measures are available. Most countries where it is endemic have adopted a programme aimed at eradication through such measures as, for instance, supplying safe drinking-water. Several countries have already made dramatic progress: the disease was eliminated from Pakistan in 1996, after seven years of concentrated efforts and in India the number of cases was reduced by more than 99% between 1995 and 1984. Worldwide, the incidence of the disease fell from 3.5 million in 1986 to approximately 122000 in 1995.

Biology

Cyclops are just visible (0.5-2 mm) and can be recognized by their jerky mode of swimming (Fig. 7.1). They feed on plankton and other small aquatic organisms. Their life cycle is adapted to their natural habitat in ponds and other accumulations of stagnant water. Female cyclops reproduce without fertilization for many generations until the habitat starts drying up. They then produce a generation consisting of both males and females, which produces fertilized eggs. Cyclops can resist drought from one rainy season to the next. Live cyclops have been observed within 30 minutes of a dry pond being filled with water; a day later they had developed into mature females (*1*). The eggs are easily dispersed to other places by animals or floods and can start new populations. The density of cyclops is often highest during the dry season when rivers, streams and ponds form shallow pools. In arid areas highest densities may be reached during the rainy season.

Public health importance

Guinea-worm disease

Because guinea-worm disease occurs only in a limited number of countries and in isolated and poor areas, and because it is rarely fatal, the disease was neglected for many years. Only relatively recently has control of the disease attracted international attention. Before control measures were systematically put in place an estimated 10 million people in poor, rural areas in sub-Saharan Africa, India, Pakistan and Yemen were infected. Until the mid-1970s it was also known in the Islamic Republic of Iran and Saudi Arabia. At present the disease mainly occurs in sub-Saharan Africa (Fig. 7.2). In 1994, over 164000 cases were reported from Africa, one-third of which occurred in Sudan, which only began extending its control and surveillance activities the same year. Outside Africa, the disease has almost disappeared: fewer than 400 cases were reported in India and about 100 cases were reported in Yemen in 1994.

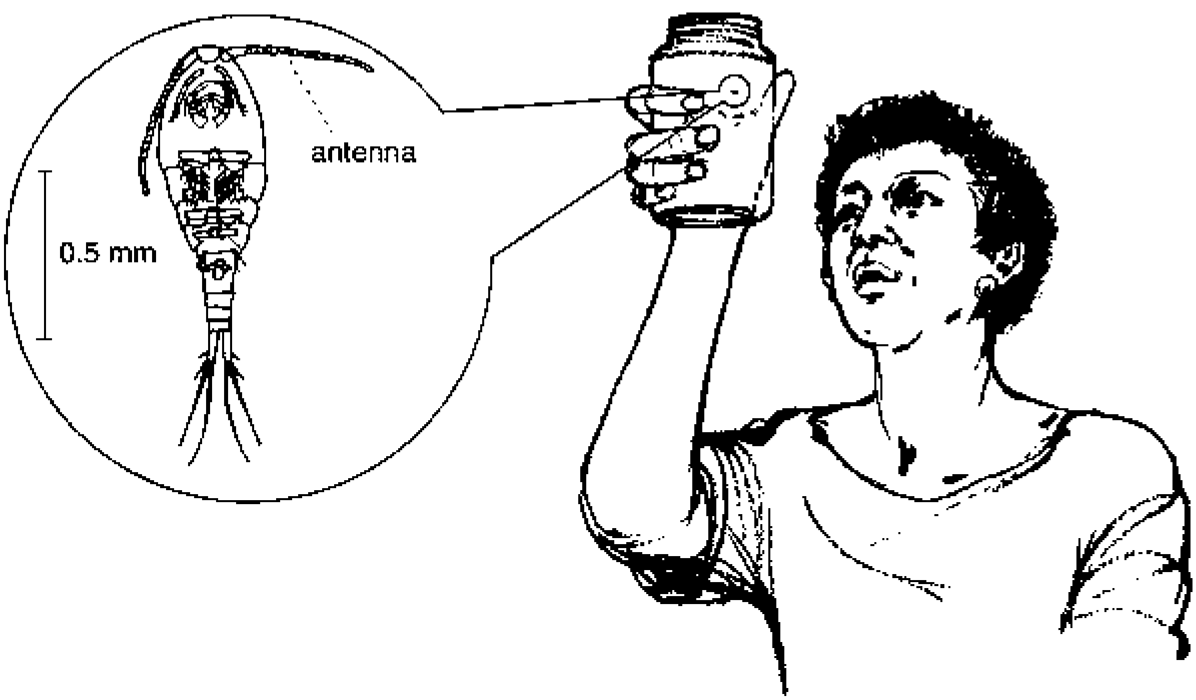

Fig. 7.1. Cyclops can be seen in pond water, collected in a glass jar, as minute dots

swimming jerkily. On the left, cyclops as it appears under a microscope.
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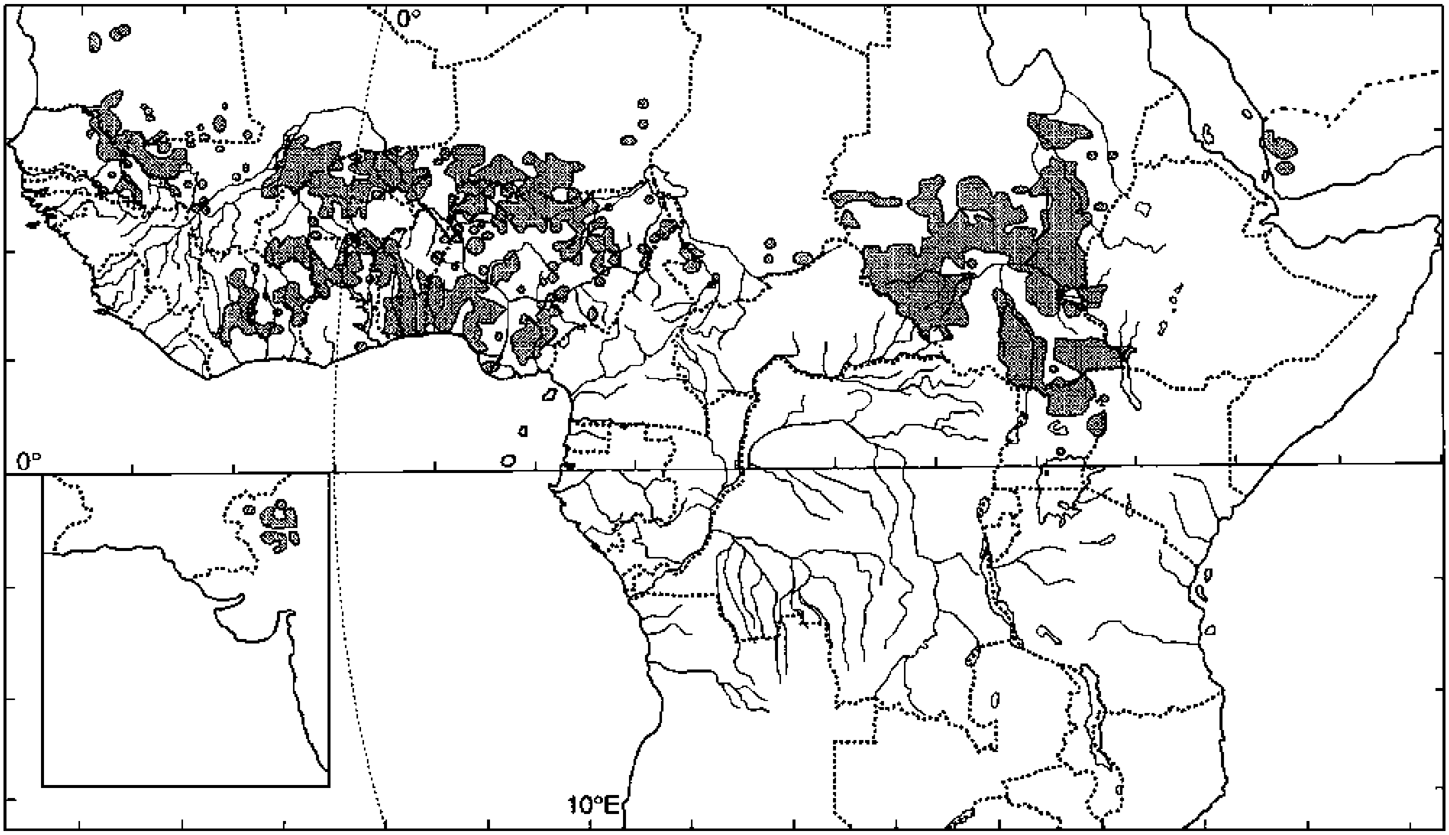


Fig. 7.2. Geographical distribution of guinea-worm disease, 1995. Insert shows the distribution of the disease in India (© WHO).
WHO 96675

Transmission

Larvae of the guinea worm enter the human body when people drink water contaminated with cyclops containing infective larvae. In the stomach, the cyclops are digested and the larvae can then move around freely. They subsequently try to penetrate the thin intestinal wall. If successful, they end up in the connective tissues of the abdomen and thorax, where they develop into adult worms, mating after three months. When mature, the female moves towards the surface, usually of the legs. About a year after the infection begins the female is ready to emerge from the body to reproduce by releasing up to three million larvae (Figs. 7.3 and 7.4).

In order to emerge, the female produces toxic substances that break down the overlying skin causing painful blisters and ulcers. The worm partly emerges and releases larvae, frequently when the affected person enters water, for example to collect drinking-water. Hundreds of thousands of small larvae are released every time the person enters water over a period of 1-3 weeks. The worm subsequently dies and is eliminated from the body over a period of 3-8 weeks.

The released larvae are not directly infective to humans. They can remain active in water for about three days and die unless they are swallowed by a cyclops. Inside the cyclops, the guinea-worm larvae develop over a period of about two weeks into a larval stage that is infective to humans.

Cyclops infected with guinea-worm larvae also suffer from the infection and tend to sink to the bottom of the water. As a result, people in humid savanna areas in sub-Saharan Africa are most likely to become infected during the dry season when water levels are lowest and they scoop to the bottom of ponds or wells in order to obtain water (Fig. 7.5).

Sites where people are at risk of infection

Guinea worm occurs only in areas where the water temperature is above 19 °C for part of the year. At greatest risk are communities that depend on ponds, cisterns and stepwells for drinking-water.

Sites suitable for transmission are accumulations of water where:

- infected people enter the water;
- the water is stagnant and cyclops species, which can transmit the parasite, are present;

- the water is used regularly as drinking-water.

Typical examples are hand-dug water-holes in West Africa, stepwells in India, pools in dry river beds and temporary accumulations of water in fields in agricultural areas (Figs. 7.6-7.8).

Seasonal fluctuations in transmission

In dry areas in sub-Saharan West Africa and in western India, peak transmission occurs at the onset of the rainy season. Farmers are then planting their crops and drinking-water is collected from rain-filled pools in the fields. Transmission decreases at the end of the rainy season when these ponds dry out.

Fig. 7.3. Life cycle of guinea worm (by Taina Litwak for the United States Agency for International Development's VBC Project).
WHO 96677

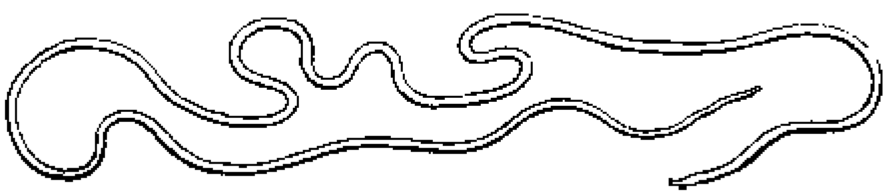


Fig. 7.4. The adult female worm of *Dracunculus medinensis* is white, between 30 and 120 cm long and about 0.2 cm wide (© WHO).

Fig. 7.5. In the dry season when the water level in village ponds drops, the cyclops are concentrated in a small quantity of water and are more likely to be picked up.

In the more humid savanna areas of West Africa, transmission occurs mainly during the dry season. In the rainy season there are so many places with surface water that transmission is less likely to occur. In the dry season the drinking-water supply is limited to only a few village ponds where conditions for transmission are more favourable.

Clinical signs and symptoms

The first signs of an infection with dracunculiasis become apparent when the female worm is ready to emerge, about a year after infection. A localized swelling appears at the spot where the worm will emerge (Fig. 7.9). The swelling itches and a burning sensation is felt. A blister appears a few days later. Accompanying symptoms may be fever, nausea, vomiting and diarrhoea. When the blister is submerged in water the female worm is stimulated to expel larvae. The discharge containing the larvae is sometimes visible as a whitish fluid. The worm lies just below the skin and its hind part protrudes slowly from the blister in order to release all the larvae it contains. This process may take 1-3 weeks, after which the worm dies. Sometimes the worms do not emerge and become calcified. Calcified worms can often be seen and palpated through the skin, and can be detected by X-rays.

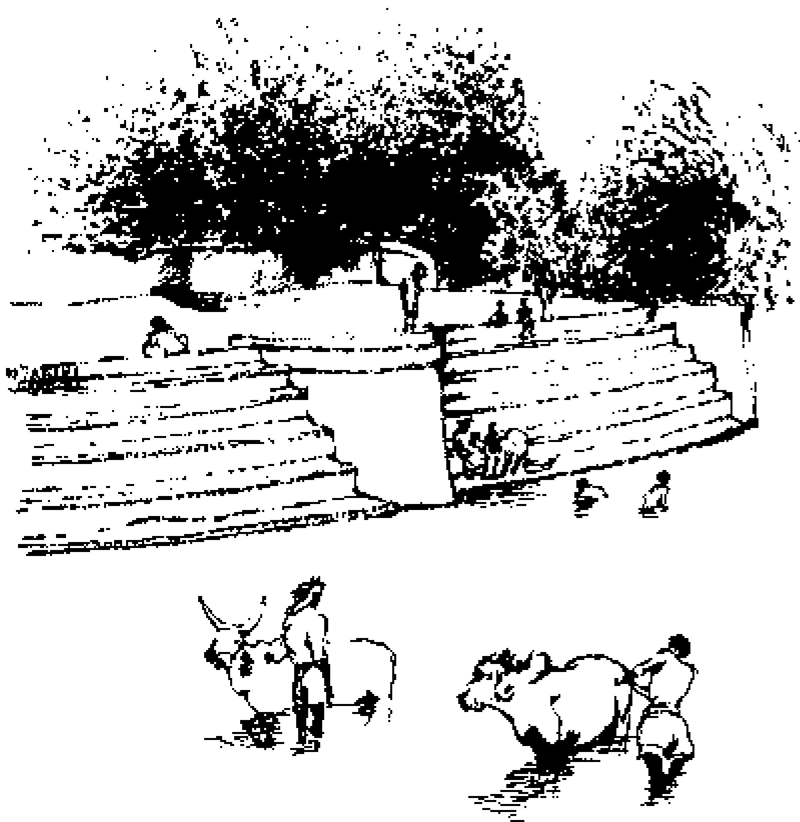


Fig. 7.6. In India, stepwells are typical transmission sites.

Fig. 7.7. Stagnant water pools in a dry river bed are favourable breeding sites for cyclops and may become transmission sites if used as a source of drinking-water.

Fig. 7.8. Small ponds that have been deepened or water holes that have been excavated to collect rainwater are the most important transmission sites of guinea worm in rural Africa.

The people most affected are those in whom the guinea worm emerges near a joint, for example the knee. Such infections may cause arthritis and permanent crippling. Large abscesses can occur if a worm ruptures and releases larvae into the tissues below the skin.

In about 90% of cases the worms are found in the lower limbs but they can also emerge from the hands, scrotum, breasts, tongue and other parts of the body. Usually only one worm emerges from an infected person but there have been reports of infection with up to 30 worms.

Generally, infections cause much pain and temporary crippling, usually lasting between three weeks and six months; the destruction of joints can cause permanent disability. The emergence of the guinea worm usually coincides with a season when agricultural activities are in progress.

Treatment, prevention and control

There is no natural immunity against guinea worm and no effective drugs or vaccines are available to prevent or treat the disease. The main aim in dealing with infected people is to prevent and treat secondary infections (abscesses, tetanus, septicaemia) and arthritis. The only available treatment is to extract the worm. This has to be done very slowly to prevent the worm from breaking. Only a few centimetres can be pulled out each day. Certain local drugs or medicinal plants are often used to reduce the burning pain in an attempt to facilitate extraction.

A traditional method of preventing the worm from withdrawing inwards is to attach it to a thread tied to the leg (Fig. 7.10). Another commonly used method is to attach the protruding part of the worm to a matchstick, which is twisted round daily until the whole worm has been extracted.

The wound should be cleaned and disinfected daily. A tight bandage should cover it completely to prevent infection of the open ulcer. The bandage also serves as a reminder not to submerge the wound in water and may prevent the release of larvae into water if the wound is submerged. Serious bacterial infections can be treated with antibiotics. Tetanus toxoid should be administered to patients with open ulcers. Severe inflammation is sometimes treated by surgical removal of the worm and pus.

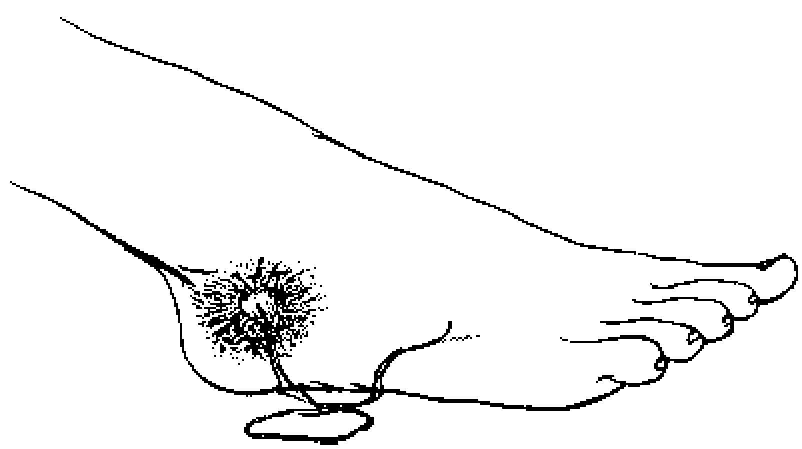


Fig. 7.9. Infection with guinea worm results in an itching and burning swelling on a leg or other part of the body, developing within a few days into a blister and an open sore. The worm emerges at the bottom of the ulcer.

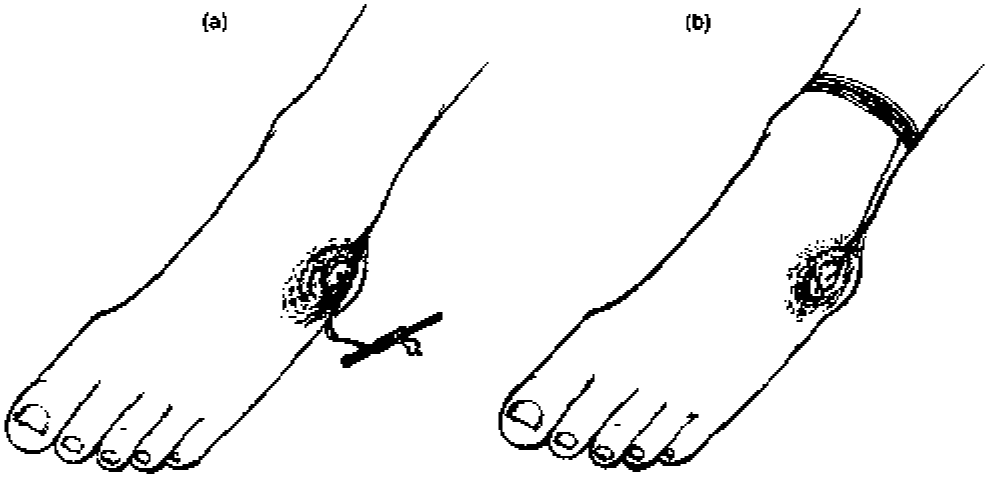


Fig. 7.10. Guinea worms can be extracted slowly by attaching to a string or rolling around a match or small stick to prevent them from withdrawing inwards.

Guinea-worm disease can be controlled by controlling the cyclops in water sources used for drinking, avoiding the swallowing of cyclops and preventing contamination of sources of drinking-water by infected people.

Eradication of guinea-worm disease

Because of the nature of its life cycle the parasite is very vulnerable to small changes in the environment and it is not unrealistic to hope for its total eradication. Simple and cheap measures are available to interrupt transmission. New infections have to be prevented only for a period of a year in order to make the disease disappear completely. The World Health Organization, other international organizations and governments of most countries where the disease is endemic are striving to eradicate it (*2*, *3*). Health education and the organization of eradication programmes based on the active involvement of communities are essential. The support of villagers can readily be obtained because of the unmistakable diagnosis of the infection and its painful and incapacitating effects. Eradication programmes could include, after extensive health education, the training of villagers to dress wounds, provide water filters to community members, and implement simple environmental management measures, such as filling and draining of ponds.

All agricultural and educational projects in areas of endemicity should include the filtering of drinking-water and the keeping of guinea-worm patients out of water while the worms are evident. This should significantly improve the results of the projects in terms of higher food production and better school attendance. Rural water supply projects should give priority to villages where guinea-worm disease is endemic.

Control measures

Effective prevention and control of dracunculiasis requires the education of community members.

Prevention of patient-water contact

People with an emerging guinea worm should never put any part of their body into water used for drinking.

Installation of safe drinking-water supplies

Communities may consider installing bore holes with pumps, piped water systems, or wells with concrete rims to prevent run-off water from draining back in (Fig. 7.11).

Filtration of drinking-water

Filtration is a very practical method, appropriate for use in all areas with guinea-worm disease (Fig. 7.12) (*4-6*). Tightly woven cotton cloth (0.15 mm pore size), available at local markets in all affected areas, can be used to filter all water intended for drinking. However, muddy water quickly clogs such cotton and preference should be given to the use of monofilament filter material. It is important always to use the filter material with the same side up, thus preventing cyclops and debris previously caught in the filter from recontaminating the water. Two-layer filters, made of two different colours of cloth, can help ensure this. A logo printed on one side of the filter serves the same purpose.

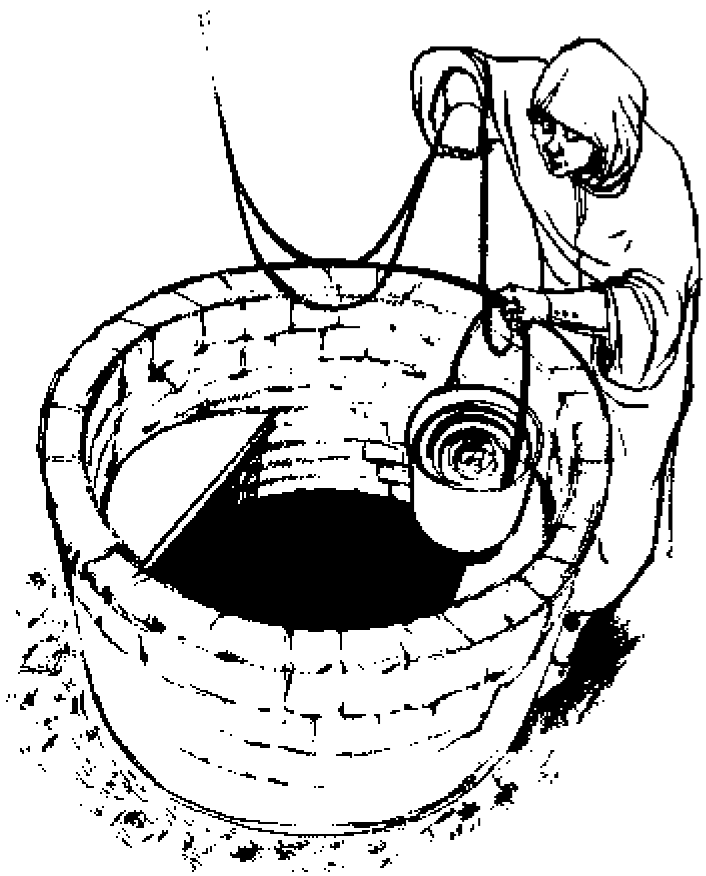


Fig. 7.11. Draw- or pit-well with rim: a safe source of drinking-water.

Fig. 7.12. Cyclops can be removed from drinking-water by pouring it through a gauze filter.

Suitable filter material

Cotton cloth

Cotton cloth with a mesh size below 0.15 mm holds back all cyclops when infected water is poured through (Fig. 7.13). However, clay particles in the water become trapped in the cotton filaments, quickly clogging the filters and proving difficult to wash out.

Synthetic gauze

Monofilament gauze (bolting cloth) with a mesh size of 0.15 mm is suitable for the filtration of water containing silt (Figs. 7.14 and 7.15). It does not become clogged and is easy to clean.

Chemical control

Cyclops can be killed by treating water sources with temephos, an insecticide that is safe in drinking-water if used at the correct dosage (*7*). This control method is expensive and requires trained personnel to calculate the volume of the water source, mix the chemical at the appropriate dosage, and so forth. It is therefore usually reserved for the treatment of small bodies of water by special eradication programmes.

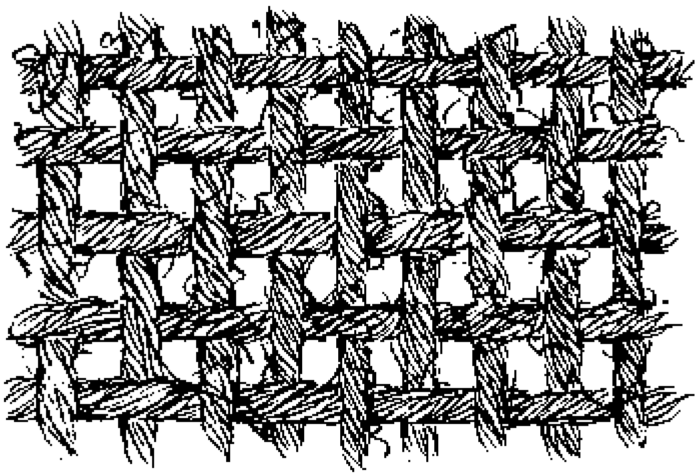


Fig. 7.13. Microscopic view of a sample of cotton cloth. The threads of cotton consist of many small filaments that trap clay particles.

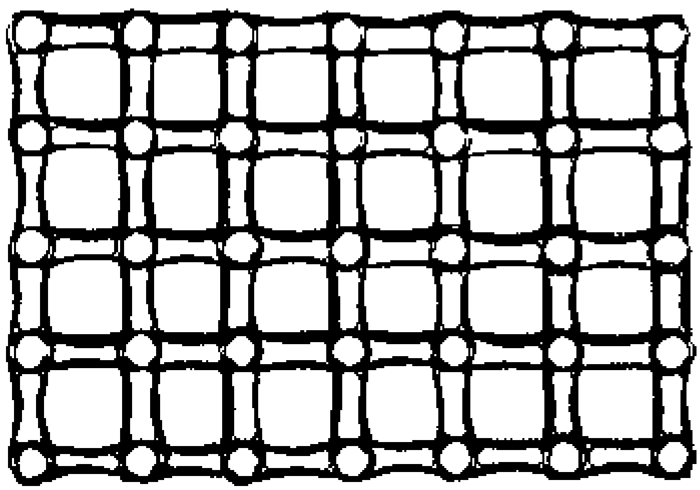
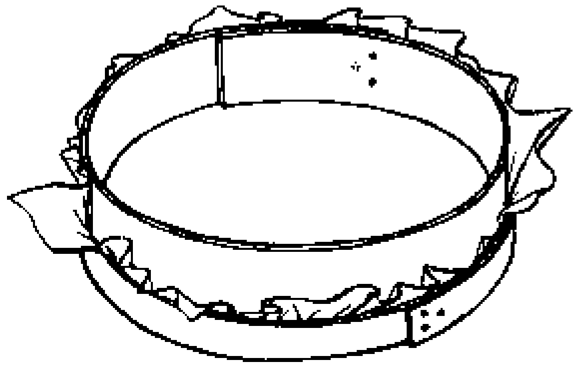


Fig. 7.14. Microscopic view of a sample of monofilament synthetic filter gauze. It does not get clogged up with dirt particles and is easy to wash.

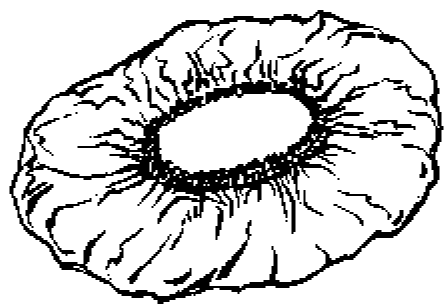
Application

The most effective formulation in common use is a 50% emulsifiable concentrate, for application at a rate of 2 ml per cubic metre of water. The contents of the pond (in m^3) should be estimated and the correct quantity of temephos mixed in a bucket with sufficient water to distribute the mixture over the entire surface (Fig. 7.16).

Fig. 7.15. Suitable filter designs:



(a) a piece of gauze of about 30 x 30 cm fixed on to a frame made of pliable bark from a local tree;



(b) a circular piece of gauze with an elastic band stitched on to the rim; the filter can easily be fitted over the mouth of a water container.

Fig. 7.16. A solution of temephos is thrown over the surface of a pond to control cyclops.

The insecticide should be applied just before or at the onset of the transmission season. It may have to be reapplied every 4-6 weeks throughout the transmission season.

Boiling of drinking-water

Boiling is a simple and effective method for killing cyclops in drinking-water. However, it is time-consuming and requires firewood (which may be scarce) and a fireproof receptacle.

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Chapter 8 - Freshwater snails

Intermediate hosts of schistosomiasis and foodborne trematode infections

Many species of freshwater snail belonging to the family Planorbidae are intermediate hosts of highly infective fluke (trematode) larvae of the genus *Schistosoma* which cause schistosomiasis, also called bilharziasis, in Africa, Asia and the Americas. The infection is widespread, and although the mortality rate is relatively low, severe debilitating illness is caused in millions of people. It is prevalent in areas where the snail intermediate hosts breed in waters contaminated by faeces or urine of infected persons. People acquire schistosomiasis through repeated contact with fresh water during fishing, farming, swimming, washing, bathing and recreational activities. Water resources development schemes in certain areas, particularly irrigation schemes, can contribute to the introduction and spread of schisto-somiasis.

The snails are considered to be intermediate hosts because humans harbour the sexual stages of the parasites and the snails harbour the asexual stages. People serve as vectors by contaminating the environment. Transfer of the infection requires no direct contact between snails and people.

Freshwater snails are also intermediate hosts of foodborne fluke infections affecting the liver, lungs and intestines of humans or animals.

Biology

Some 350 snail species are estimated to be of possible medical or veterinary importance. Most intermediate hosts of human *Schistosoma* parasites belong to three genera, *Biomphalaria, Bulinus* and *Oncomelania*. The species involved can be identified by the shape of the outer shell. Simple regional keys are available for the determination of most species. The snails can be divided into two main groups: aquatic snails that live under water and cannot usually survive elsewhere (*Biomphalaria, Bulinus*), and amphibious snails adapted for living in and out of water (*Oncomelania*). In Africa and the Americas, snails of the genus *Biomphalaria* serve as intermediate hosts of *S. mansoni* (Fig. 8.1). Snails of the genus *Bulinus* serve as the intermediate hosts of *S. haematobium* in Africa and the Eastern Mediterranean, as well as of *S. intercalatum* in Africa. In south-east Asia, *Oncomelania* serves as the intermediate host of *S. japonicum*, and *Tricula* as the intermediate host of *S. mekongi*. Among the snail intermediate hosts of trematodes, the species belonging to the genus *Lymnaea* are of importance in the transmission of liver flukes. *Lymnaea* species may be either aquatic or amphibious (Fig. 8.2).

Life cycle

All species of *Biomphalaria* and *Bulinus* are hermaphrodite, possessing both male and female organs and being capable of self- or cross-fertilization. A single specimen can invade and populate a new habitat. The eggs are laid at intervals in batches of 5 - 40, each batch being enclosed in a mass of jelly-like material. The young snails hatch after 6 - 8 days and reach maturity in 4 - 7 weeks, depending on the species and environmental conditions. Temperature and food availability are among the most important limiting factors. A snail lays up to 1000 eggs during its life, which may last more than a year.

Fig. 8.1 Snail of the genus *Biomphalaria* (reproduced, with permission, from the *Bayer manual of pest control*).

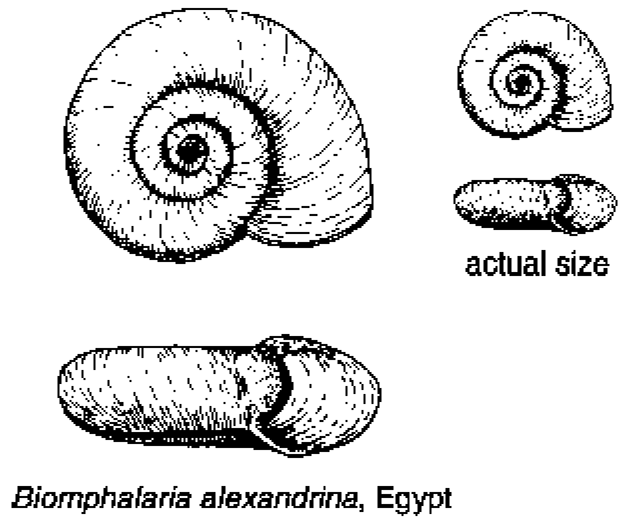
The amphibious *Oncomelania* snails, which may live for several years, have separate sexes. The female lays its eggs singly near the water margin.

Ecology

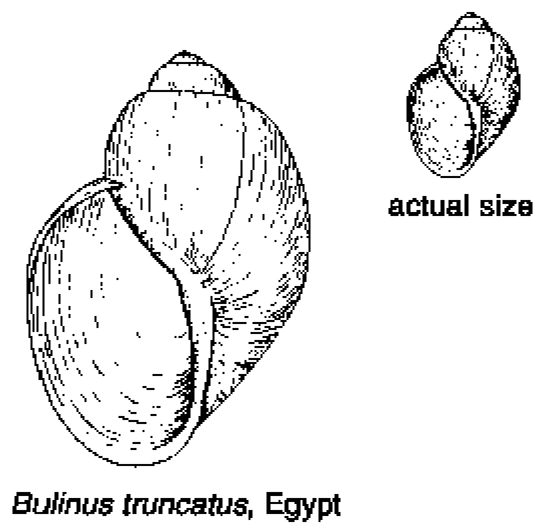
Snail habitats include almost all types of freshwater bodies ranging from small temporary ponds and streams to large lakes and rivers. Within each habitat, snail distribution may be patchy and detection requires examination of different sites. Moreover, snail densities vary significantly with the season. In general, the aquatic snail hosts of schistosomes occur in shallow water near the shores of lakes, ponds, marshes, streams and irrigation channels. They live on water plants and mud that is rich in decaying organic matter. They can also be found on rocks, stones or concrete covered with algae or on various types of debris. They are most common in waters where water plants are abundant and in water moderately polluted with organic matter, such as faeces and urine, as is often the case near human habitations. Plants serve as substrates for feeding and oviposition as well as providing protection from high water velocities and predators such as fish and birds.

Most aquatic snail species die when stranded on dry land in the dry season. However, a proportion of some snail species are able to withstand desiccation for months while buried in the mud bottom by sealing their shell opening with a layer of mucus. Most species can survive outside water for short periods.

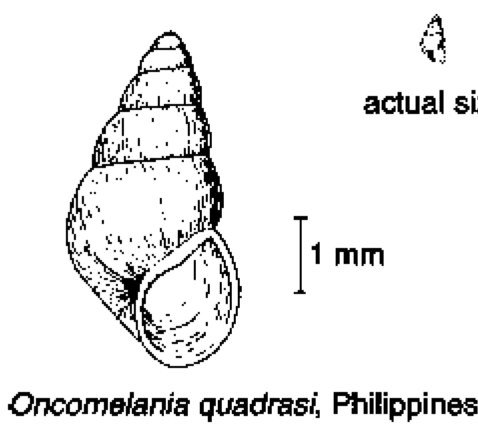
Fig. 8.2 Shells of the medically important snail genera:



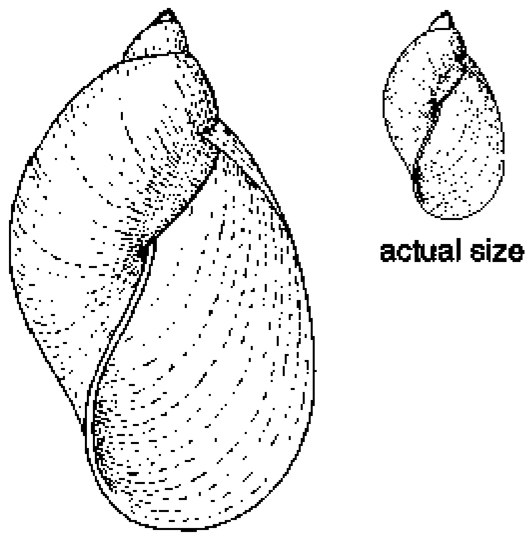
(a) *Biomphalaria*; (© WHO)



(b) *Bulinus*; (© WHO)



(c) *Oncomelania*; (© WHO)



(d) *Lymnaea* (© WHO)

For reproduction, temperatures between 22 °C and 26 °C are usually optimal, but *Bulinus* snails in Ghana and other hot places have a wider temperature range. The snails can easily survive between 10 °C and 35 °C. They are not found in salty or acidic water.

In most areas, seasonal changes in rainfall, water level and temperature cause marked fluctuations in snail population densities and transmission rates. Reservoirs that contain water for several months of the year in Sahelian Africa can be intensive transmission sites of urinary schistosomiasis during a very limited period, because surviving *Bulinus* species rapidly recolonize the reservoirs after the rains start.

Oncomelania snails can survive periods of drought because they possess an operculum capable of closing the shell opening. In the temperate zone they can survive for 2 - 4 months, in the tropics much less. They live both in and out of water in humid areas such as poorly tilled rice fields, sluggish streams, secondary and tertiary canals of irrigation systems, swamps and roadside ditches. The vegetation in these sites is important in maintaining a suitable temperature and humidity. Their food is similar to that of aquatic snails but they also feed on plant surfaces above water.

Public health importance

Schistosomiasis

Schistosomiasis is one of the most widespread of all human parasitic diseases, ranking second only to malaria in terms of its socioeconomic and public health importance in tropical and subtropical areas. It is also the most prevalent of the waterborne diseases and one of the greatest risks to health in rural areas of developing countries.

In 1996 schistosomiasis was reported to be endemic in 74 tropical countries, and over 200 million people living in rural and agricultural areas were estimated to be infected. Between 500 and 600 million people were considered at risk of becoming infected.

As a mainly rural, often occupational disease, schistosomiasis principally affects people who are unable to avoid contact with water, either because of their profession (agriculture, fishing) or because of a lack of a reliable source of safe water for drinking, washing and bathing. As a result of a low level of resistance and intensive water contact when playing and swimming, children aged between 10 and 15 years are the most heavily infected. Increased population movements help to spread the disease, and schistosomiasis is now occurring increasingly in periurban areas.

Although most people in areas of endemicity have light infections with no symptoms, the effects of schistosomiasis on a country's health and economy are serious. In several areas (e.g., north-eastern Brazil, Egypt, Sudan) the working ability of the rural inhabitants is severely reduced as a result of the weakness and lethargy caused by the disease.

Major forms and distribution of schistosomes

Five species of the trematode parasite are responsible for the major forms of human schistosomiasis. In 1996 intestinal schistosomiasis caused by *Schistosoma mansoni* was reported from 52 countries in Africa, the eastern Mediterranean, the Caribbean and South America. Oriental or Asiatic intestinal schistosomiasis, caused by *S. japonicum* or *S. mekongi*, was reported to be endemic in seven Asian countries. Another form of intestinal schistosomiasis caused by *S. intercalatum* was reported from 10 central African countries. Urinary (or vesical) schistosomiasis, caused by *S. haematobium*, was reported to be endemic in 54 countries in Africa and the eastern Mediterranean (Figs. 8.3 and 8.4).

Life cycle and transmission

On reaching water, the eggs excreted by an infected person hatch to release a tiny parasite (a miracidium) that swims actively through the water by means of fine hairs (cilia) covering its body. The miracidium survives for about 8 - 12 hours, during which time it must find and penetrate the soft body of a suitable freshwater snail in order to develop further (Figs 8.5 and 8.6).

Once inside the snail, the miracidium reproduces many times asexually until thousands of new forms (cercariae) break out of the snail into the water. Depending on the species of snail and parasite, and on environmental conditions, this phase of development may take 3 weeks in hot areas, and 4 - 7 weeks or longer elsewhere. The fork-tailed cercariae can live for up to 48 hours outside the snail. Within that time they must penetrate the skin of a human being in order to continue their life cycle.

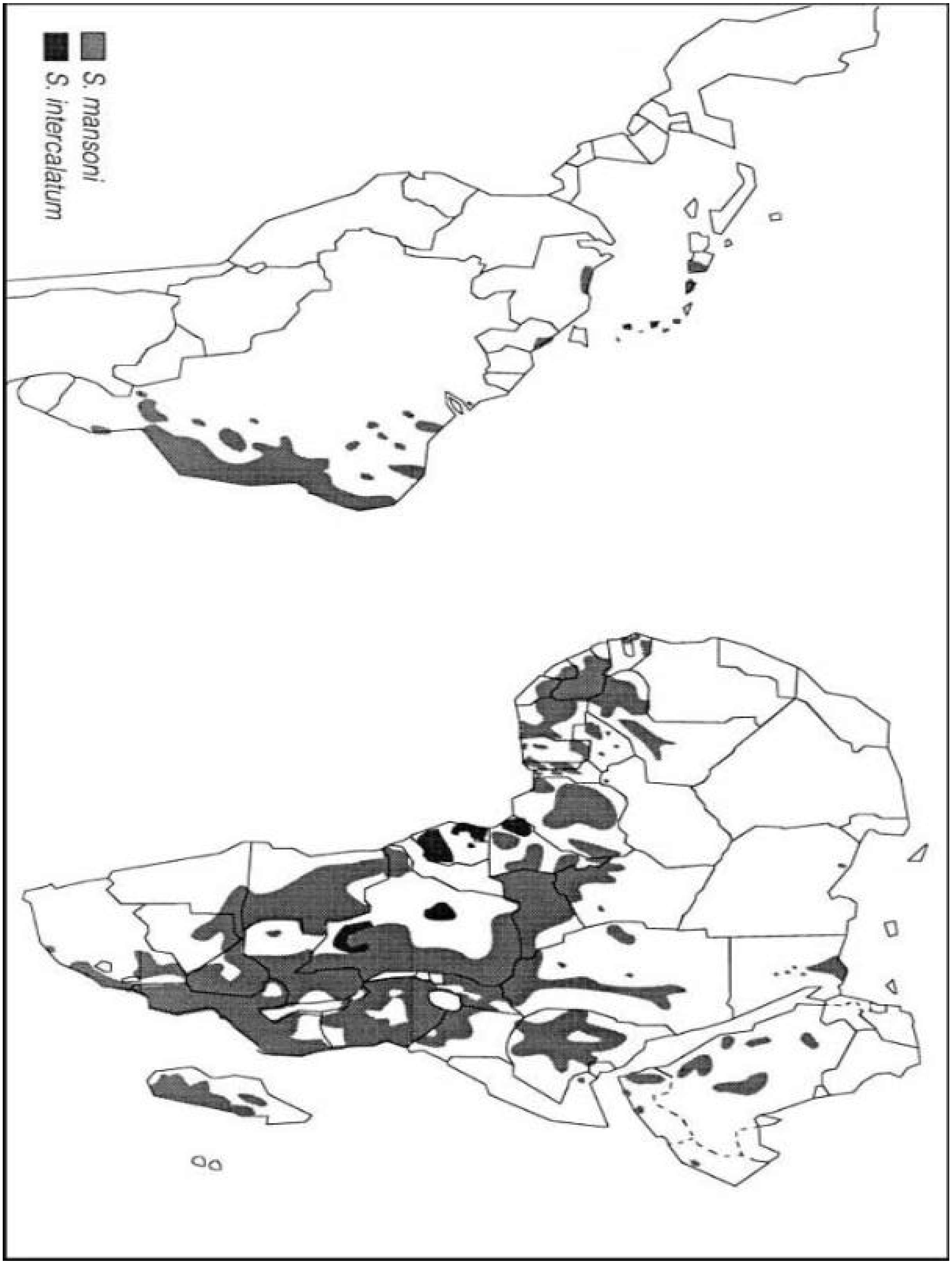


Fig. 8.3 Global distribution of schistosomiasis due to *Schistosoma mansoni* and *S. intercalatum*, 1993 (© WHO)

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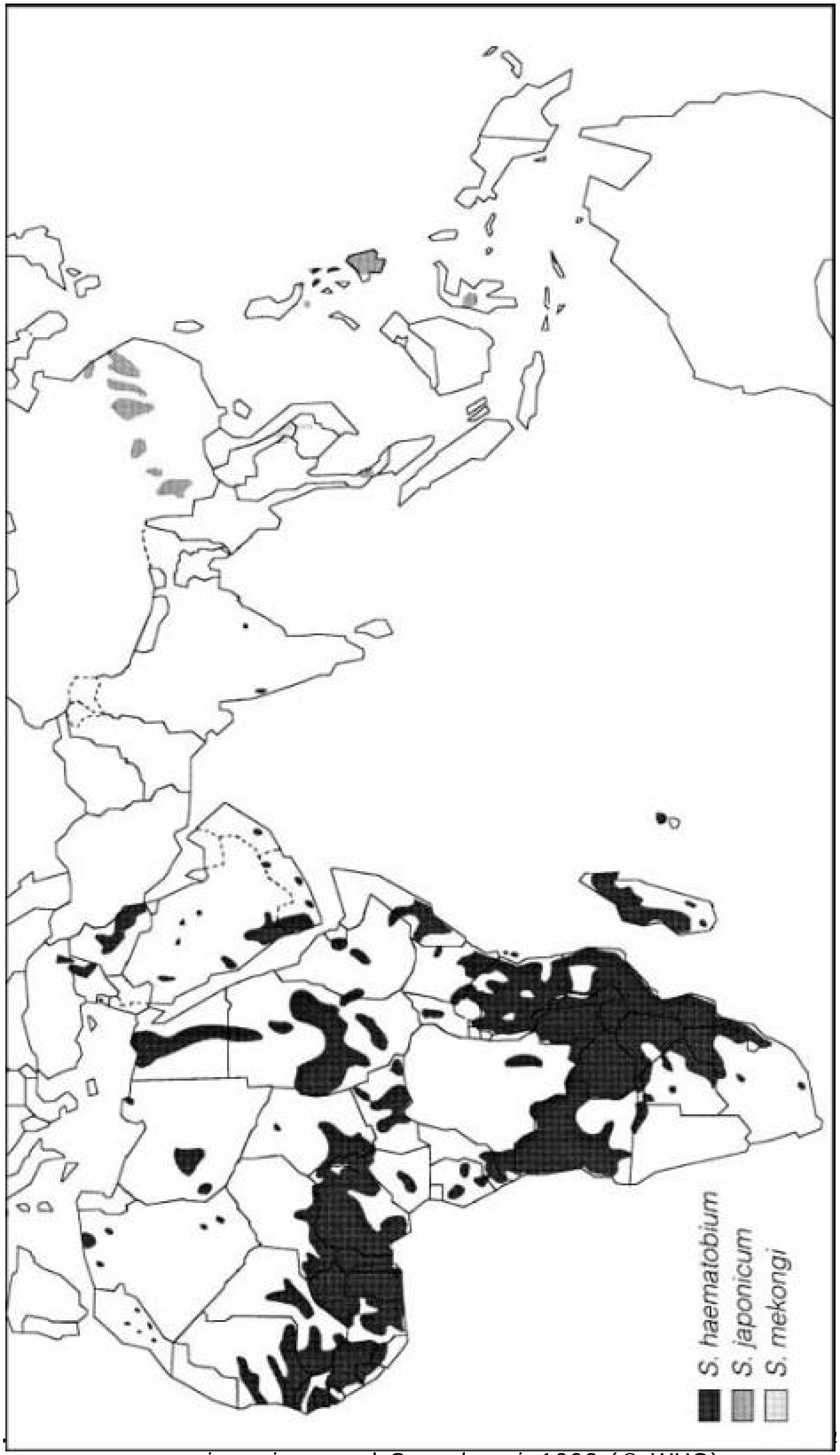

Fig. ... *tobium, S. japonicum* and *S. mekongi*, 1993 (© WHO)

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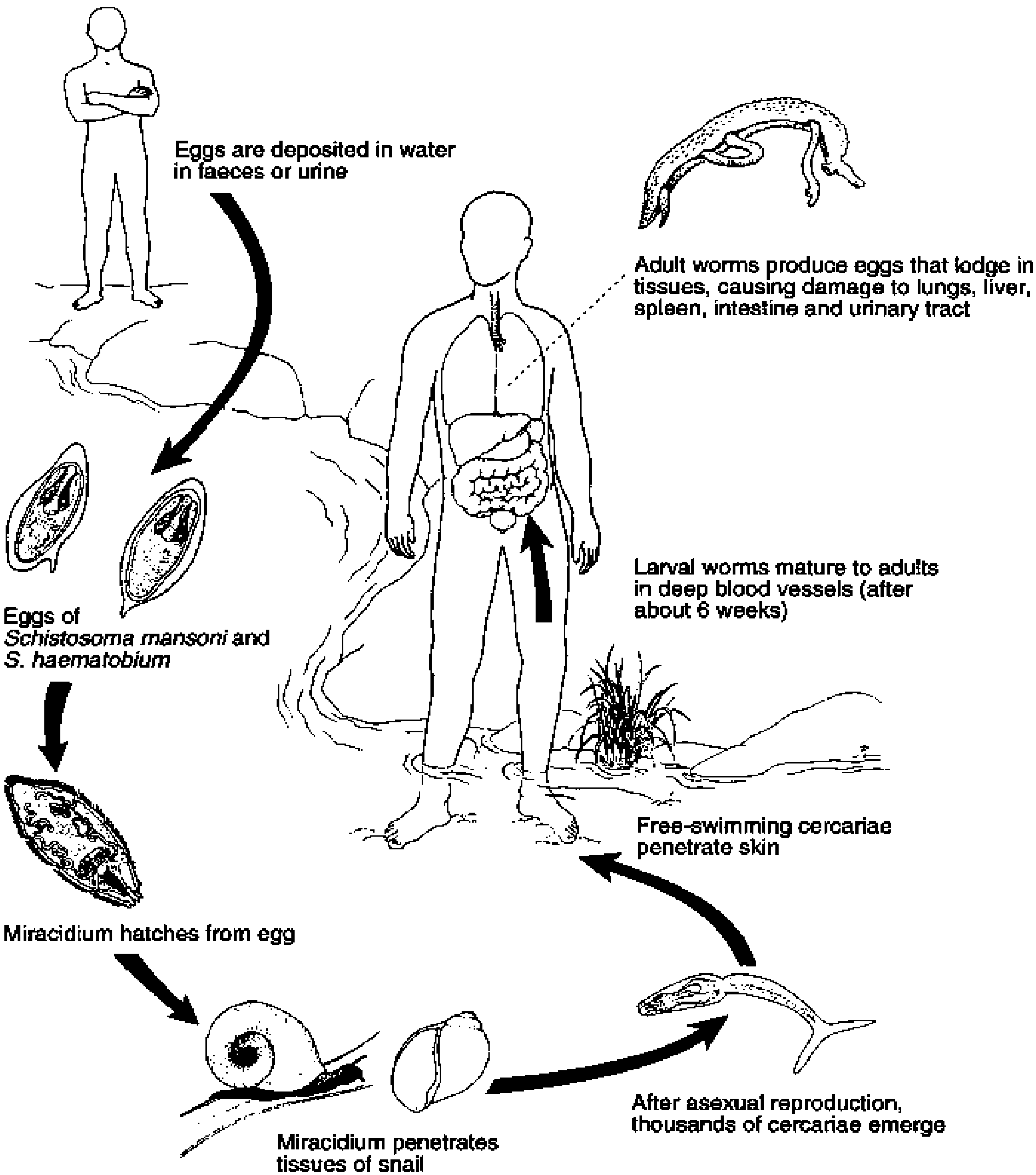


Fig. 8.5 Life cycle of schistosomes (by Taina Litwak for the United States Agency for International Development's VBC Project).

WHO 96691

As the cercaria penetrates the skin, it loses its tail. Within 48 hours it penetrates the skin completely to reach the blood vessels. This process sometimes causes itching, but most people do not notice it.

Within seven weeks the young parasite matures into an adult male or female worm. Eggs are produced only by mated females. Male and female adult worms remain joined together for life, a period of less than five years on average but 20 years has been recorded. The more slender female is held permanently in a groove in the front of the male's body. Once eggs are produced, the cycle starts again.

In intestinal schistosomiasis the worms attach themselves to the blood vessels that line the intestines; in urinary schistosomiasis, they live in the blood vessels of the bladder. Only about half of the eggs leave the body in the faeces (intestinal schistosomiasis) or urine (urinary schistosomiasis); the rest remain embedded in the body where they cause damage to organs.

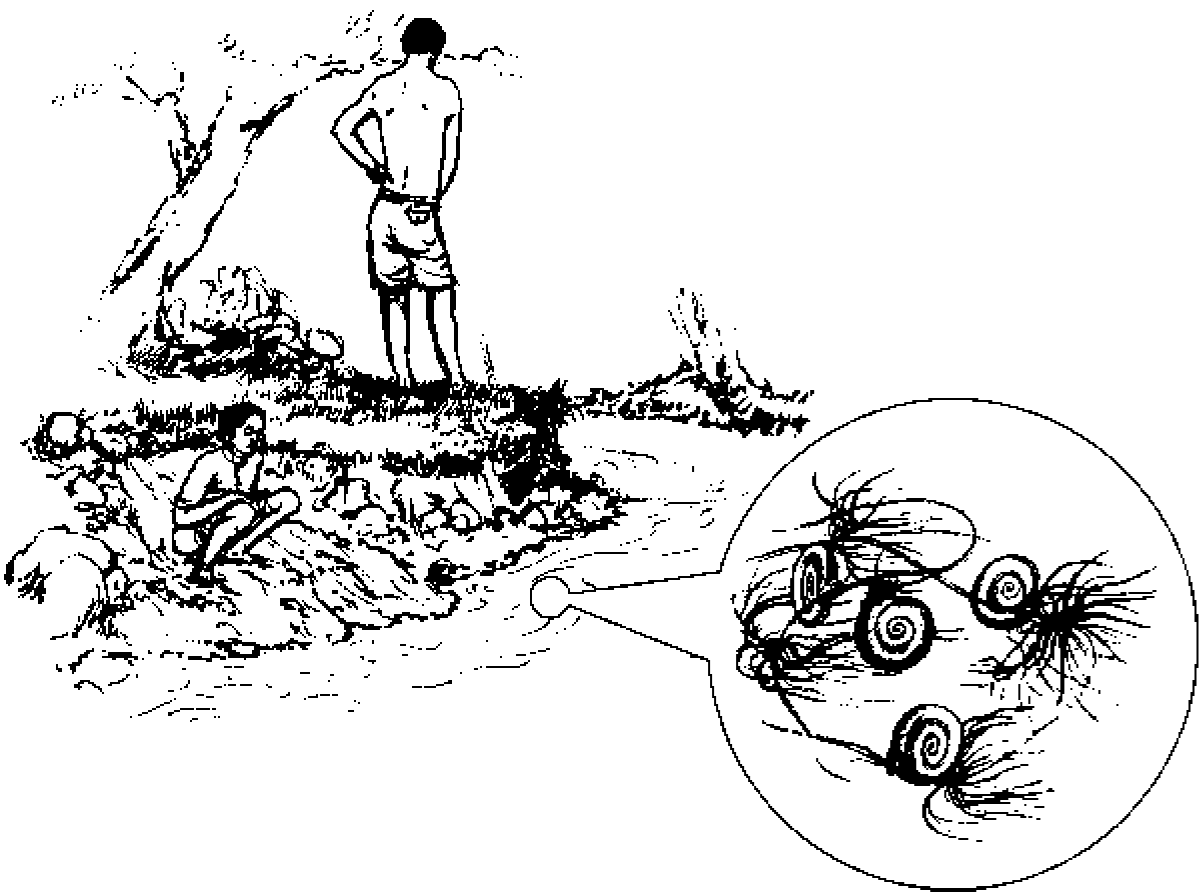


Fig. 8.6 Transmission of schistosomes. Eggs enter the water when infected people urinate in it or defecate on the water's edge. Freshwater snails are required for the development of the infective stage of the parasite which subsequently infects people entering the water.

Clinical signs and symptoms

Reactions occur to schistosome eggs that are not passed out in the urine or stools but become lodged in body tissues. The symptoms are related to the number and location of the eggs.

In urinary schistosomiasis (caused by *S. haematobium*) the eggs cause damage to the urinary tract and blood appears in the urine. Urination becomes painful and there is progressive damage to the bladder, ureters and kidneys. Bladder cancer is common in advanced cases.

Intestinal schistosomiasis (caused by *S. mansoni, S. japonicum* and *S. mekongi*) develops more slowly. There is progressive enlargement of the liver and spleen (Fig. 8.7) as well as damage to the intestine, caused by fibrotic lesions around the schistosome eggs lodged in these tissues and hypertension of the abdominal blood vessels. Repeated bleeding from these vessels leads to blood in the stools and can be fatal. *S. intercalatum* infects the lower intestinal tract.

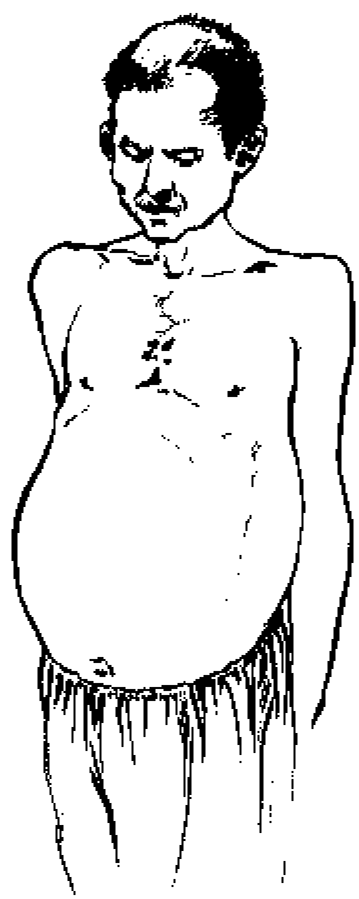


Fig. 8.7 Enlargement of the liver and spleen may occur in people with untreated intestinal schistosomiasis.

Swimmer's itch

Human skin can be penetrated by cercariae that normally develop in birds. The larvae die in the skin causing an allergic reaction known as swimmer's itch. This problem is seen in many temperate areas, in people who bathe in fresh, brackish and salt water, where infected aquatic birds shed faeces in water populated by appropriate snail hosts.

Diagnosis

Modern techniques for detecting schistosome eggs under the microscope are simple and inexpensive. A simple syringe filtration technique (using filter paper, polycarbonate or nylon filters) is recommended for quantitative diagnosis of urinary schistosomiasis. This technique allows urinary egg counts to be performed on up to 130 samples per hour.

Researchers using this technique on children in Ghana, Kenya, Liberia, Niger, the United Republic of Tanzania and Zambia reported that children with more than 50 *S. haematobium* eggs per 10ml of urine often have blood in their urine (haematuria). This sign is evidence of bladder disease caused by urinary schistoso- miasis, and can be used by primary health care workers to identify children needing treatment. Urine sedimentation is also a simple and effective method for detecting *Schistosoma* eggs.

The diagnosis of intestinal schistosomiasis by counting the eggs in faecal specimens has also been simplified. A small amount of faeces, pressed through a fine nylon or steel screen to remove large debris, and placed under a piece of cellophane soaked in glycerol (Kato technique) or between glass slides (glass sandwich technique) can be quickly examined by trained microscopists.

Treatment

All people are susceptible to infection. Children have a higher rate of reinfection after treatment than adults.

Immunization is of great research interest but the probability of success is remote.

Three safe, effective drugs that can be taken orally are now available to treat schistosomiasis. Praziquantel, oxamniquine and metrifonate are all included in the WHO Model List of Essential Drugs (*1*). Praziquantel is effective in a single dose against all forms of schistosomiasis. Previously irreversible damage caused by *Schistosoma* infections can now be successfully treated with praziquantel.

Oxamniquine is used exclusively to treat intestinal schistosomiasis in Africa and South America, although *S. mansoni* is less susceptible to oxamniquine in Africa than in South America. Metrifonate, which was originally developed as an insecticide, has now proved to be safe and effective for the treatment of urinary schistosomiasis.

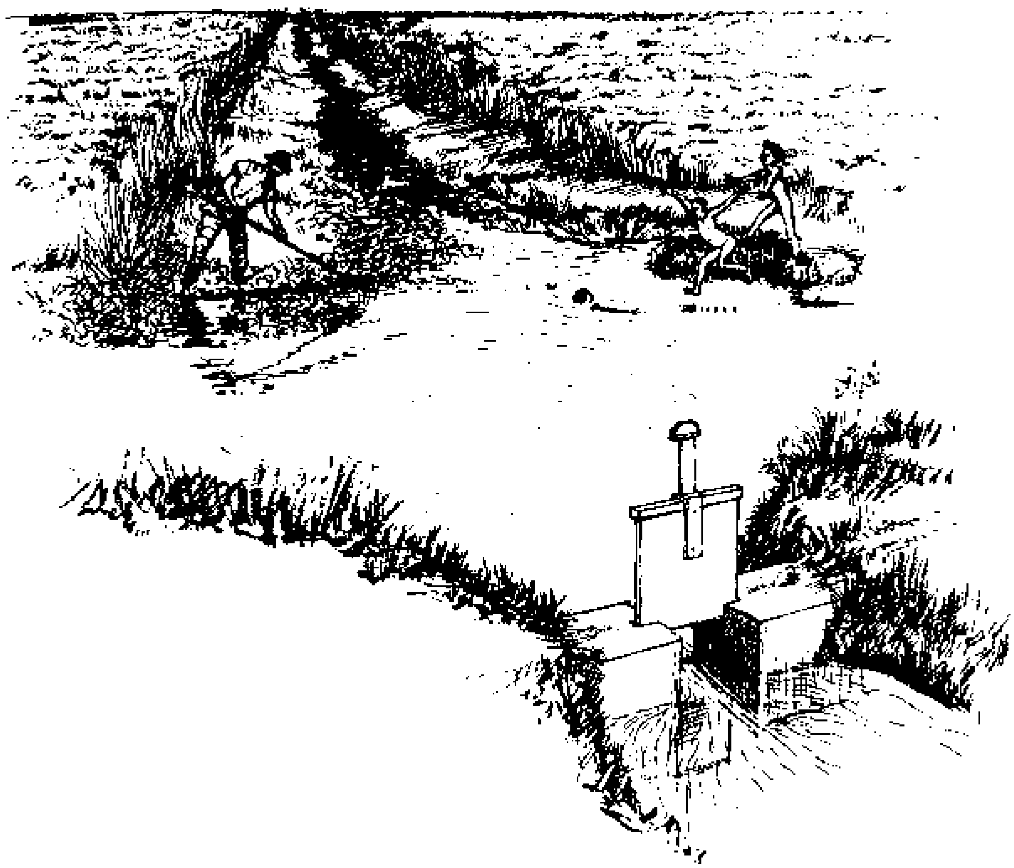
The fears of many doctors that reinfection would quickly eliminate any benefit from treatment have proved too pessimistic. Rapid identification and prompt treatment of infected people immediately reduce environmental contamination with parasite eggs. In some areas, a reduction in the number of cases is maintained for a year and a half without further intervention, but in areas of continuing transmission certain age groups (schoolchildren) may be reinfected within 4 - 6 months. Even if reinfection occurs morbidity may be reduced for a much longer time, because it usually results from prolonged infection with large numbers of parasites.

Prevention and control

Individual protection from infection (e.g. in travellers) can in principle be achieved by avoiding contact with unsafe water. However, this requires an understanding of the risk of contact with water and a knowledge of the sites where infected snails are likely to occur (Fig. 8.8). For people living in areas of endemicity, contact is often unavoidable (farmers in irrigated agricultural areas, fishermen) or difficult to prevent (playing children).

The control of the disease in known foci of transmission is possible by using one or a combination of the following measures: improved detection and treatment of sick people; improvement of sanitary facilities for safe and acceptable disposal of human excreta; provision of safe drinking-water; reduction of contact with contaminated water; and snail control.

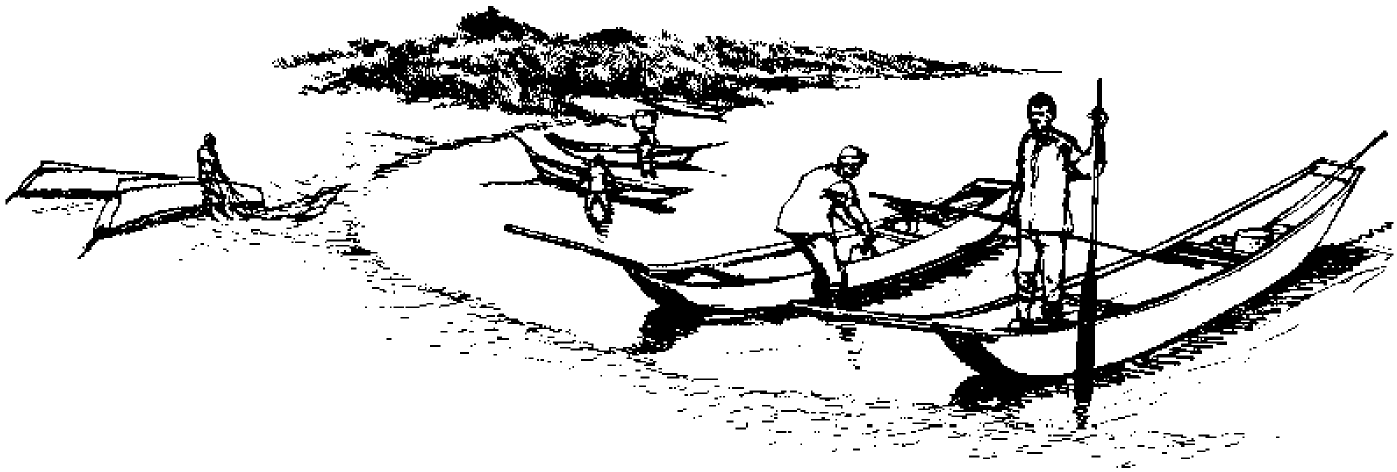
Fig. 8.8 Typical transmission sites.



(a) Drainage canal.

(b) River bank.

(c) Irrigated rice fields and surrounding drainage canals.



(d) The banks of natural and artificial lakes in Africa.

In areas with low to medium prevalence of schistosomiasis and good health services, improved case detection and treatment of reported cases of illness may be the most cost-effective approach to control.[1] In areas where the disease is highly endemic, special schistosomiasis control campaigns, involving snail control measures, might be an additional cost-effective solution (*2*). Long-term sustainable improvements have to be based on safe water supply and improvements in sanitation and hygiene. Health education is essential for community understanding and participation in the proper use and continuous maintenance of sanitary and water supply facilities.

[1] In areas where schistosomiasis caused by *S. japonicum* is endemic in south-east Asia and the western Pacific, control approaches should include the treatment of both infected persons and domestic animals because the parasite also occurs in populations of wild and domestic animals such as rodents, dogs, cats, pigs, water buffaloes, horses and cattle. Infected wild rodents may be a cause of continued transmission.

Schistosomiasis control in water resources development projects

The increasing numbers of water resources projects, essential for industrial and agricultural expansion in developing countries, are a matter of great concern to schistosomiasis experts. Water impoundments of all sizes, including man-made lakes and irrigation systems, provide excellent habitats for freshwater snails and encourage close and frequent contact between people and infected water.

Schistosomiasis and other waterborne diseases, whether introduced or spread by water development projects, can have a severe impact in economic terms (loss of labour, cost of treatment) and as regards the quality of life, and can delay the completion of projects if construction workers or the local population become infected. However, it is now possible to institute control measures from the moment such a project is planned. Examination and treatment of the population in the project area, of all employees of the development project and their families, and of potential migrant populations reduce the risk of schistosomiasis becoming a major public health problem. Good water management practices, where necessary supplemented by regular applications of molluscicide, may limit the distribution of snails. The lower the potential for transmission from the start, the smaller is the chance that serious disease will develop.

Foodborne trematode infections (3)

In 1993 at least 40 million people, largely in south-east Asia and the western Pacific, were reported to be infected by pathogenic flukes other than schistosomes. Fascioliasis, caused by *Fasciola hepatica* or *F. gigantica*, is an infection of the liver found throughout the world. Liver infections are also caused by oriental flukes in Asia (*Clonorchis sinensis, Opisthorchis viverrini* and *O. felineus*). Paragonimiasis, or lung fluke disease, occurs in Asia, West Africa, Ecuador, Peru and other South American countries. Intestinal fluke infections, caused by *Fasciolopsis buski* and many other species, occur in several Asian countries.

All trematode parasites occurring in humans are flat and leaf-shaped, ranging in size from 1mm to 30mm (up to 75mm for *Fasciolopsis*). The adults deposit eggs that are excreted with the bile, sputum or faeces. On contact with water the eggs hatch and the larvae penetrate the appropriate snail intermediate hosts (*Fasciola* and *Paragonimus*), or the eggs are ingested by the snails and hatch inside (*Clonorchis, Opisthorchis*). Each parasite develops in a specific type of snail. Free-swimming cercariae emerge from the snail and attach to a specific second intermediate host (or substrate) to form a cyst. These hosts are usually a source of food for humans, i.e. watercress, fish and crustacea.

Prevention and control are possible through food safety measures (proper cooking and washing of fish, meat and vegetables) and avoidance of contamination of the environment with excreta. For example the fertilization of fish ponds in China with unprocessed night soil has been found to be a major cause of infection with *Clonorchis* and other flukes. Pretreatment of night soil in tanks to destroy eggs and other pathogens reduces the incidence of fluke infections significantly (*4)*. Snail control measures are not cost-effective.

Praziquantel is the drug of choice for treatment of all human foodborne trematode infections except fascioliasis. *Fasciola hepatica* is described here in some detail because of its wide distribution and relative importance.

Fasciola hepatica

This fluke species occurs throughout the world and is a cause of serious economic loss in the animal husbandry industry. It is a common disease of ruminants, especially sheep, goats, cattle and buffaloes, although many other domestic and wild animals may also be infected. In comparison with animal infections, human infections are uncommon. Between 1970 and 1993, it was estimated that over 300000 clinical cases may have occurred in more than 40 countries in Europe, the Americas, Africa, Asia and the western Pacific. The fluke is 2 - 3cm in length, 0.8 - 1.3cm in width, flat and leaf-shaped.

Life cycle and transmission

The adult worm lives in the human bile duct from where the eggs pass into the intestines and are excreted with the faeces. The eggs can remain viable in moist faeces for up to nine months or even longer. The larva (miracidium) hatches about two weeks after the eggs enter the water. It enters a snail and develops to produce large numbers of free-swimming cercariae which attach themselves to aquatic plants such as watercress and form cysts.

If the cysts are ingested by humans or animals, metacercariae emerge in the duodenum, penetrate the intestinal wall and reach the liver through the lymph or the body cavity where they remain for two or three months. Once they reach maturity, they migrate to the bile duct. The longevity in humans may be more than 10 years. Humans are infected by ingesting cyst-infested salads, eating raw liver or drinking water containing cysts.

Clinical signs and symptoms

Infection of the liver is difficult to diagnose because the symptoms are variable and resemble those of other diseases. A major symptom is chronic inflammation of the bile ducts. Bleeding of the bile duct can be a complication. People who have recently eaten raw liver may acquire infection of the pharynx, which is more easily diagnosed.

Diagnosis

Fasciola hepatica eggs can be detected by examination of faeces using a microscope (see p. 345).

Treatment and prevention

Treatment is possible with bithionol. Triclabendazole is being considered for registration by drug regulatory agencies in a number of countries. Infection can be prevented by not drinking unboiled or unfiltered water and by not eating raw liver and unboiled or unwashed vegetables. Snail control measures are not cost-effective.

Control measures

In addition to case detection and the treatment of sick people at first-line health facilities, measures should be taken to reduce or prevent transmission of schistosomiasis. The installation of a safe water supply is, in most areas, the most cost-effective control measure. Health education is essential to ensure community involvement in the construction and use of such facilities.

Avoidance of contact with snail-infested waters

It is important to provide water for drinking, bathing and washing clothes. Good village water supplies with pumps and pipes or pit-wells encourage people to stay away from streams and ponds that are infested (Fig. 8.9).

The health authorities should provide information on the safety of open waters. People should avoid swimming, wading, washing or bathing in water suspected of infestation. However, because detailed information is generally not available, it is safer to consider all freshwater bodies in endemic areas as potential transmission sites.

For agricultural workers at constant risk of infection, periodic examination and treatment may be the most feasible approach to disease control.

Improved sanitation

Defecation or urination in or near open waters should be avoided so that snails have less chance of becoming infected. Latrines or toilets should be constructed, and children should be taught to use them (Fig. 8.10). (For more information on latrines, see Chapter 1.)

Snail control

With the introduction of new and safer drugs for the treatment of schistosomiasis, and, in many places, improvements in water supply and sanitation facilities, snail control is perhaps employed less often as a means of combating the disease. However, it remains an important and effective measure, especially where transmission occurs to a significant extent through children playing in water. This type of water contact is not likely to be changed through health education and the provision of safe water supplies. Prior to undertaking snail control measures, health authorities should screen water for the presence of snail intermediate hosts.

Snails can be controlled indirectly by reducing their habitat or directly by removing them. Where these measures are not sufficient to eliminate snail populations the use of chemicals that kill the snails (molluscicides) may be considered.

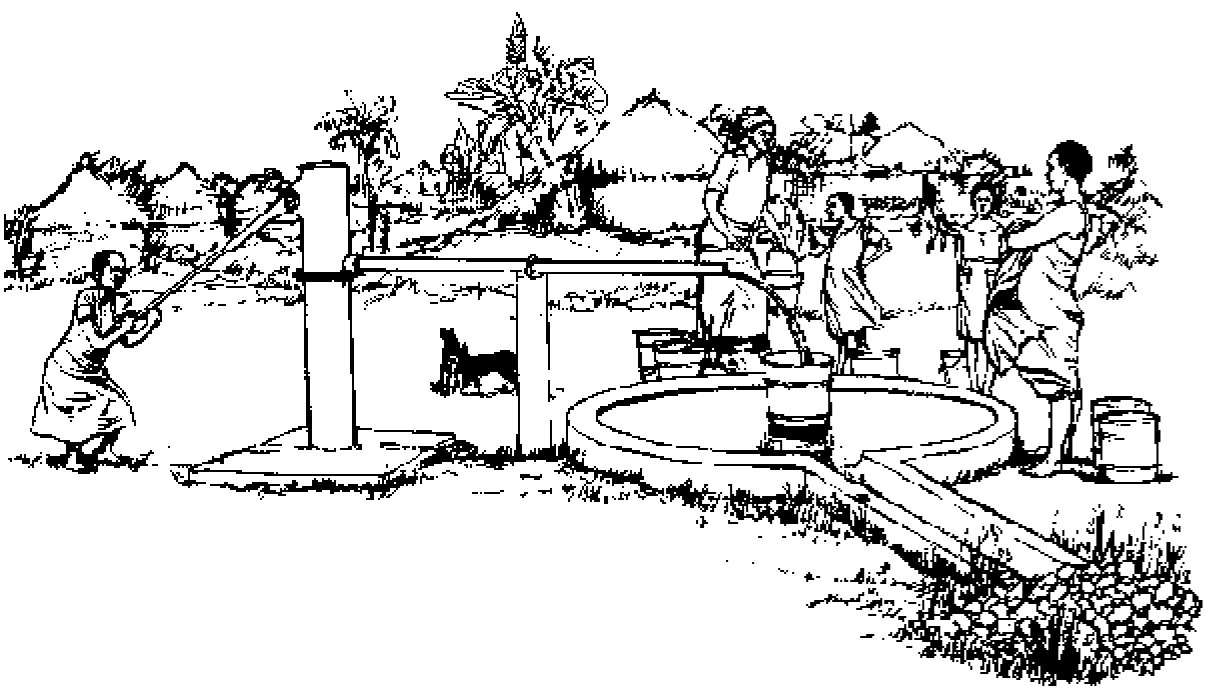


Fig. 8.9 A piped water supply with pumps, pit-wells and taps helps people to stay away from water that is infected.

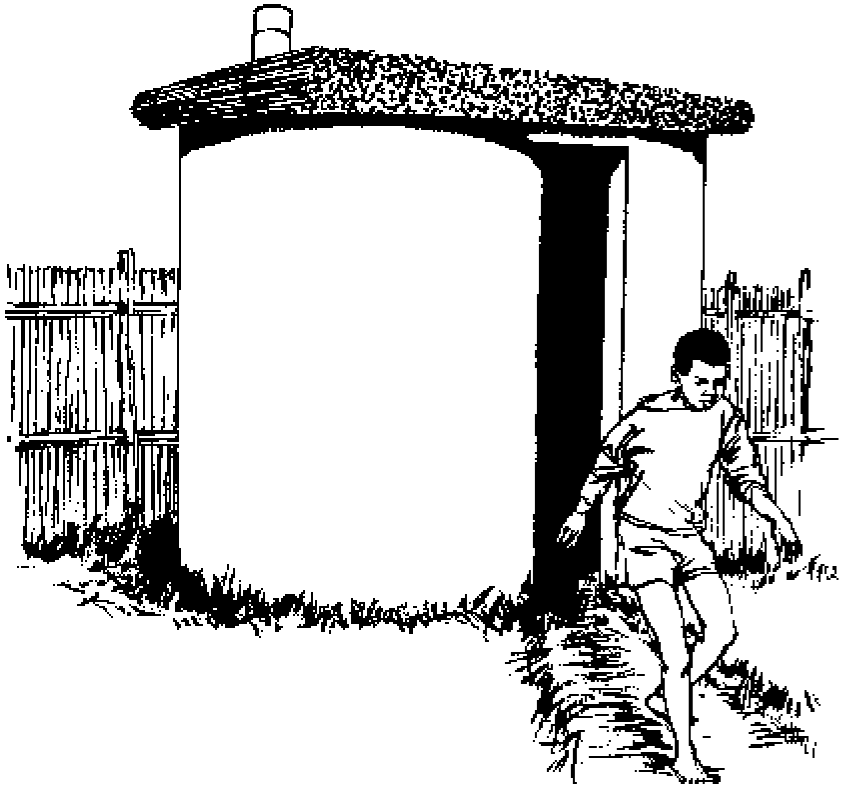


Fig. 8.10. The use of pit latrines prevents the transmission of schistosomiasis.

The decision to do this, and the activity itself, must be the responsibility of technically qualified people.

The use of molluscicides has been and still is the most important method for controlling snail hosts. It is most effective against aquatic species of the genera *Bulinus* and *Biomphalaria*. Molluscicides are less effective against the amphibious *Oncomelania* species that transmit *S. japonicum*; environmental management measures are usually more cost-effective.

Snail control may be carried out by special teams or by primary health care personnel with some training in the epidemiology and control of schistosomiasis. Where transmission sites are well known, small in number and easily accessible, the community may also play an active role in control activities.

Environmental management

The methods of environmental management include drainage, filling in, and the lining of canals with concrete. These methods are generally expensive but long-lasting.

Reduction of snail habitats

Snails need vegetation for food, shelter and a substrate for their eggs. The removal of vegetation in irrigation ditches and canals reduces the number of snails. However, to clear manually, someone usually has to get into the water which is dangerous, while mechanical clearance is very expensive. The cleaning of canals may also help in the control of other diseases, including malaria, and may improve the effective use of irrigation water. A disadvantage of this method is the need for frequent repetition. Where sufficient resources are available, canals can be lined with cement to prevent or reduce the growth of vegetation. People can also remove plants from places where children swim or where clothes or dishes are washed. Under certain conditions the plant-eating Chinese grass carp (*Ctenopharyngodon idella*) may be suitable for the biological control of aquatic plants (see Chapter 1).

Alteration of water levels and flow rates

Where water quantity is not a limiting factor, raising and lowering water levels and increasing flow rates can disturb snail habitats and their food sources. Rapid complete drainage reduces the amount of vegetation and kills the snails by desiccation. This method may be of interest in areas with irrigated crops.

Elimination of breeding sites

Borrow-pits, small pools and ponds serving no special purpose may be drained or filled if they are found to be important sites for the transmission of schistosomiasis.

Removal and destruction

Snails can be removed from canals and watercourses with dredges and crushed or left to die of desiccation. This happens in irrigated areas of Egypt and Sudan as a beneficial side-effect of efforts to improve the flow of water by removing mud from canal bottoms.

Biological control

The possibility of controlling snails biologically has attracted some attention but cannot currently be recommended (*5*).

Chemical control

In the past, molluscicides were often applied on an area-wide basis. This costly and environmentally harmful method has been replaced by focal application (*6*, *7*). Studies are first carried out to identify sites and seasons of transmission, and only at such sites are chemicals applied periodically. Applications are usually restricted to places frequently used by the local population for swimming, washing, bathing and so on.

Currently only one chemical molluscicide, niclosamide, is acceptable for operational use in snail control programmes. Other molluscicides, including some of plant origin, are being evaluated. Because of its high cost, niclosamide is used only sparingly in a few local control programmes. At low concentrations it is highly toxic to snails and their egg masses. For practical use a concentration of 0.6 - 1 mg/l is recommended with an exposure time of eight hours.

The compound is safe to handle and after dilution is non-toxic to water plants and crops; however, it is very toxic to fish. Fish killed by the molluscicide can be safely eaten. When used focally and seasonally, molluscicide application should not cause any serious negative impact on the environment.

The use of molluscicides in general has a number of disadvantages:

- because of the need for repeated applications a long-term commitment is required;

- the chemicals are costly, and good supervision of application by trained personnel is essential;

- they have adverse effects on non-target organisms, particularly fish;

- snails are able to bury themselves or temporarily leave the water to escape the chemicals, necessitating repeated application.

For further information on the use of molluscicides, see reference *8*.

Application

Niclosamide is available as a 70% wettable powder or a 25% emulsifiable concentrate. The latter formulation spreads very well in standing water when mixed with diesel oil at a ratio of 8.5 parts of 25% emulsifiable concentrate to 1.5 parts of diesel oil. One gram of the active ingredient is contained in 1.43g of the powder, or 4g or 4ml of the liquid.

In stagnant water

Where water is stagnant, such as in swamps and ponds and behind dams, applications are best carried out using a sprayer. The use and operation of a hand-compression sprayer are discussed in Chapter 9. Knapsack sprayers are also suitable. Mixtures of the wettable powder formulation for spraying should be constantly agitated.

Recommended dosages of niclosamide for stagnant water are 0.4mg/l of the 25% emulsifiable concentrate formulation and 0.6mg/l of the wettable powder formulation.

The amount to be sprayed on the water surface is calculated as follows. The volume of water in the pond is obtained by multiplying the average depth by the length and width. The depth can be estimated using a measuring stick weighted at the bottom and attached to the middle of a long string at the top. The stick stands upright from the bottom of the pond when the ends of the string are pulled from opposite sides.

In small ponds the molluscicide should be sprayed equally over the whole surface. In larger ponds only the margins need be treated.

Simple field equipment is available for measuring the concentration of the chemical in water to check whether applications have been made correctly.

In flowing water

Molluscicides introduced into flowing water are carried away immediately from the point of application. Because the chemical needs to be in contact with the snails long enough to kill them (preferably eight hours or more), it needs to be applied over a sufficiently long period. It is recommended that flowing water be treated for eight hours with a dosage of 0.6mg/l of the 25% emulsifiable concentrate formulation or 1mg/l of the wettable powder formulation.

The release of molluscicide into flowing water is commonly carried out by a drip-feed technique using a drum dispenser (Fig. 8.11), which delivers a constant flow for a number of hours. It should be set up at narrow or turbulent points in a stream or canal to ensure complete mixing of the chemical with the water. The chemical is carried away with the flow and distributed throughout the system. Sufficient chemical has to be introduced at the source to ensure that it is still of high enough concentration to kill the snails and their eggs at the end of the system.

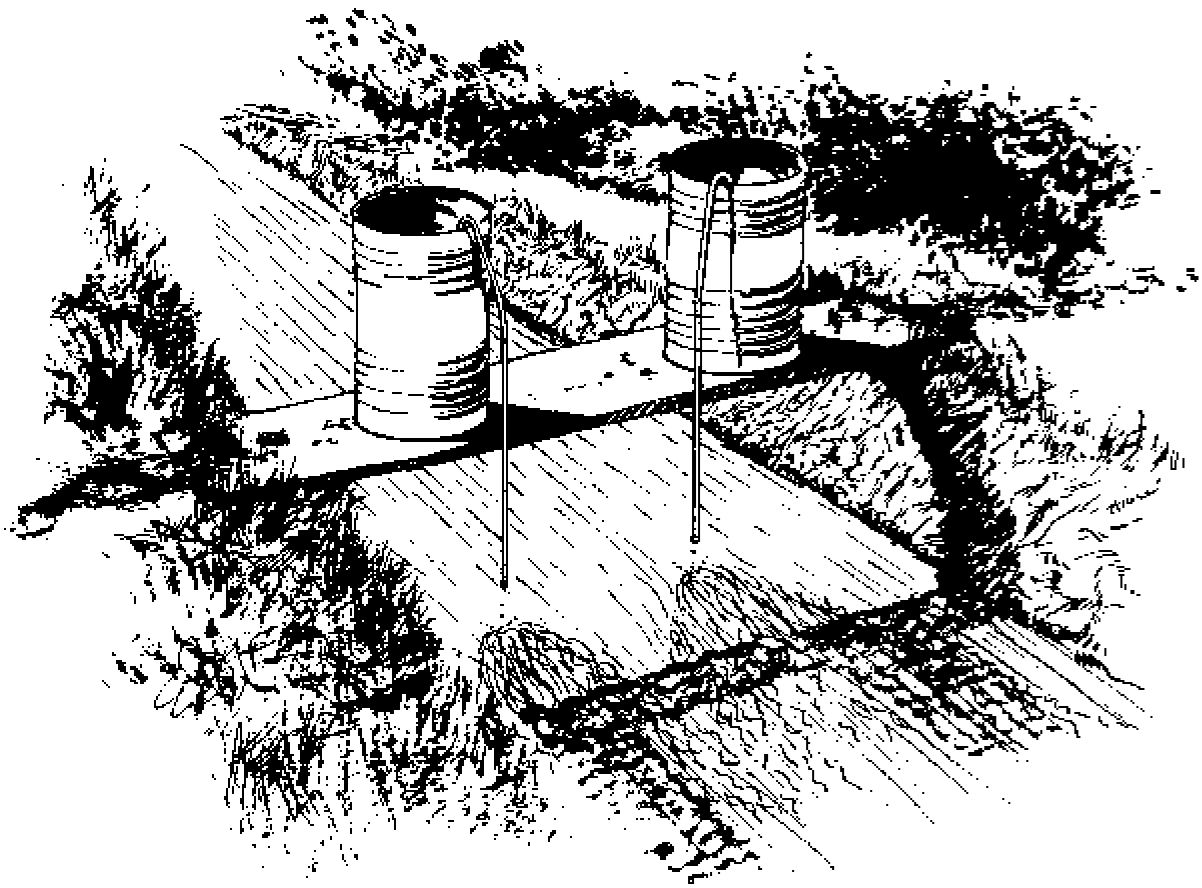


Fig. 8.11. Chemical control of schistosomiasis: molluscicide is slowly released from a barrel into flowing water.

In canals the water velocity can be estimated by recording the time for a floating object to travel a certain distance. In rivers and streams this method is inaccurate because of alternating sections of stagnant water and rapid flow. Further calculations to obtain the appropriate amount of chemical are shown in the box below.

Application of molluscicide using a constant-head dispenser

Niclosamide 70% wettable powder at 1mg/l (active ingredient) is applied for eight hours:

1. Water volume to be treated per second (m^3/s): $Q = V \times D \times W$ where:

V = water velocity in m/s
D = water depth in metres
W = width of canal in metres

2. Total amount of molluscicide (in grams) needed:

$Q \times 100/70 \times 60 \times 60 \times 8$

3. Discharge from head dispenser: F litres/s

4. Mixing solution in head dispenser:

$[Q\ (m^3/s) \times 100/70\ (g/m^3)]/F\ (l/s) = 100/70 \times Q/F\ (g/l)$

Note: the average water velocity in the entire cross-section of the canal is about 85% of the maximum flow velocity measured at the surface by observing a floating object. Therefore the amount of niclosamide in equation 2 needs to be multiplied by 0.85.

The drum dispenser should be filled with the amount of molluscicide mixture in water required for constant application over eight hours. The molluscicide is released from the barrel through a hose or tap. The correct quantity is obtained by adjusting the tap or by widening or narrowing the diameter of the hose with an adjustable clamp. If the suspension is prepared with a wettable powder formulation, frequent stirring is needed to prevent sedimentation of the chemical.

Focal application in a canal in Sudan

A slightly different application procedure was found effective in a village in Sudan, where transmission of schistosomiasis occurred along a nearby stretch of irrigation canal. One kilogram of niclosamide 70% wettable powder was mixed with 10 litres of water and applied 300m upstream of the village. Application for 40 minutes resulted in a concentration of 2 - 3g/m^3, which kept the stretch of canal free of snails for 4 - 6 weeks. After this time, the application had to be repeated.

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Chapter 9 - House-spraying with residual insecticides

One of the most important advances in the control of insects during this century was the development of insecticides that remain active over extended periods. The first insecticide with such long-lasting or residual properties, DDT, was developed during the Second World War. Soon afterwards it was discovered that DDT sprayed on walls and ceilings in houses killed insects for several months.

Spraying with residual insecticide became particularly important in the control of the mosquito vectors of malaria, which often rest on walls before and after feeding. In South America, wall-spraying became the most important method for controlling the triatomine bugs, vectors of Chagas disease, which live in cracks. Residual wall-spraying is also effective against bedbugs and some species of indoor biting sandflies, the vectors of leishmaniasis. It can be used in the control of *Culex* and *Aedes* mosquitos, the vectors of filariasis and dengue, but is not very effective against these species, partly because they tend to rest indoors on objects that cannot be sprayed, like curtains, clothes and furniture.

Cockroaches, fleas, soft ticks, biting mites and other pests can be controlled by spraying residual insecticides on their breeding, hiding and resting places. In Africa, tsetse flies, the vectors of sleeping sickness, can be controlled by spraying their resting and breeding sites in vegetation.

Problems with house-spraying in malaria control programmes

In general, wall-spraying with DDT was effective in reducing malaria wherever it was carried out correctly. However, a number of problems were eventually encountered, among them the following:

- development of resistance by the target insects to DDT and other insecticides;
- outdoor biting and resting habits of some vector mosquitos;
- inadequate sprayable surfaces in some houses;
- custom of people in some areas to sleep outside during the hot season.

Another important problem was poor acceptance of the method by the community. Populations living in areas where house-spraying was carried out often did not see much benefit from spray operations. They became increasingly reluctant to allow spray teams to have access to their living quarters and to accept the sometimes bad-smelling and unsightly insecticide deposits in their houses unless there was a substantial reduction in disease incidence.

Organizing, managing and financing large-scale spray operations over extended periods proved problematic in many countries. To spray large numbers of houses once or twice a year requires considerable organization and many people, vehicles and spraying machines. After an initially successful period many operations became increasingly inefficient and ineffective. The maintenance of such programmes appeared to be beyond the means of most developing countries. In the 1970s it became clear that malaria eradication by house-spraying was not feasible and that a reorganization of the control programmes was needed. Spraying was continued only in areas with sufficient resources and where it could be expected to be effective. Control programmes no longer aimed to eradicate malaria but to reduce the incidence to such a level that it was no longer a major public health problem. A flexible approach was clearly needed, using a variety of techniques of vector control and disease management.

Organization of spraying

House-spraying was traditionally carried out by specialized spray programmes employing a large number of personnel. It became clear that alternative vector control methods would have to be simpler and cheaper to allow for decentralization and more involvement of district health services and communities.

Although emphasis was placed on finding alternatives to house-spraying, it continues to be one of the most effective vector control methods in a number of places. Changing the way in which spraying operations are organized may solve several of the earlier problems.

Health education is needed to make communities and other groups aware of the responsibility they have for their own health and of the possibilities for taking action. In many areas, farmers possess spray pumps for the spraying of crops. In small communities, farmers could be trained to spray houses, perhaps with some minor modifications to their equipment. In other cases the health services could provide the spraying equipment and community health workers or other community members could be trained to carry out spraying. All the houses in a small community can be sprayed in one or two weeks, and spray equipment could therefore be shared by several communities.

A community-based approach avoids most of the problems related to the transportation of spray teams and equipment. Acceptance and cooperation by house owners are higher with better health education and more involvement in planning. The cost for personnel is much reduced although the local health service or a community-based organization may have to give the spray workers some financial or other compensation. The health services, however, have to be strengthened in order to provide health education as well as the supervision and evaluation of activities. The responsibility for equipment, spare parts and insecticide also has to lie with the health services. Vector control experts are needed to provide advice on spraying techniques and equipment, appropriate insecticides and the time of spraying.

Factors that determine the efficacy of wall-spraying

Mosquito resting behaviour

The longer the indoor resting period, the higher is the efficacy of the spray treatment. A resting period of a few hours is usually sufficient to kill most mosquito and sandfly species. It is also important to know the preferred resting sites: some species only rest on the lower parts of walls, others on roofs. Clearly, only the resting areas need to be sprayed.

Mosquito susceptibility to insecticides

Some mosquito species have developed resistance to certain insecticides, most notably DDT, and other insecticides have to be used. Resistance should be suspected if repeated observations are made of mosquitos that survive after resting on a sprayed surface for at least half an hour. The use of a WHO susceptibility test kit[a] may confirm such observations.

Suitability of wall or roof surfaces for spraying

Walls made of unrendered earth or mud absorb much insecticide at the surface where mosquitos rest. Some soil walls contain chemicals that increase the pH, causing rapid breakdown of some insecticides. Roofs made of thatch or brushwood provide openings within which insects rest but where they cannot be reached by sprays. The best surfaces for spraying are non-absorbent, such as hard wood and painted surfaces (see Chapter 1).

Suitability of insecticides

The aim is to kill insects after they land and rest on the sprayed surface. Suitable insecticides should therefore not have a repellent action. A few insecticides kill on contact but also have an airborne effect without repelling the insects (bendiocarb, propoxur, pirimiphos methyl, fenitrothion). Formulation is important: emulsifiable concentrates are not generally suitable.

Cooperation of house owners

Indoor house-spraying has given rise to many problems and misunderstandings between spray teams and house owners. Good health education is needed to explain the reason for spraying. Those who are responsible for planning and carrying out spray activities have to respect local customs and beliefs.

[a] Available on request from Vector Control Research Unit, School of Biological Sciences, Malaysia Sains University (USM), Penang, Malaysia.

Insecticides for residual spraying

Insecticides can be directed against the larval stages of mosquitos, which live in water, or against free-living adult stages. In the latter case they can be applied in two ways:

• **Release into the air in the form of a vapour or aerosol**, by means, for example, of mosquito coils and aerosol spray cans and by space-spraying. This method knocks down or kills flying and resting insects immediately after they absorb the particles by inhalation or contact, but offers only brief protection.

• **Application to a surface as a spray or deposit or impregnation for prolonged action**. Residual insecticides kill insects that land on or crawl over a treated surface. The duration of action depends on many factors, such as the nature of the surface, the insecticide, its formulation and the dosage. Examples are insecticidal dusts used against lice and fleas, impregnated mosquito nets and residual spraying of the walls in a house.

Different insecticides are suitable for different application methods. For example insecticides that evaporate quickly at ambient temperature are not suitable for residual application on walls; they may, however, be suitable for use in vaporizers or space sprays.

Characteristics of good residual insecticides

A residual insecticide should be:

• **Highly toxic to target insects.** Insecticides may lose their effectiveness if the target insects develop resistance. From time to time, samples of the target insect should be collected and checked for the development of resistance. If resistance is observed another insecticide without cross-resistance has to be used.

• **Long-lasting on a given surface.** The toxicity should remain high over a sufficiently long period to prevent the need for frequent reapplication, which is costly and time-consuming.

• **Not repellent or irritant to target insects** to ensure that the insects pick up a lethal dose.

• **Safe to humans and domestic animals.** There should be no danger to spray workers, inhabitants or animals accidentally contaminated with the insecticide during or after spraying.

• **Acceptable to house owners.** Some insecticide formulations are less acceptable because of their smell or because they leave unattractive deposits on walls.

• **Stable during storage and transportation; mix well with water; harmless to spraying equipment.**

• **Cost-effective.** Calculation of the cost should be based on how the insecticide is applied, at what dosage and how many times a year.

Resistance

Resistance is a common result of insecticide use and selection pressure on the insect population. When resistance does emerge, the choice of a replacement insecticide will depend on the mechanism of resistance, known susceptibility, cost-effectiveness and availability. Ideally, the available insecticides should be used as part of an overall strategy to maximize the useful life of each product.

DDT used to be the most commonly applied insecticide and can still be employed where mosquito vectors are susceptible.

Where insects are resistant to DDT, the next insecticide of choice is usually one of the organophosphorus compounds, especially malathion. If the target insects have developed resistance to malathion, fenitrothion, which is more expensive and more hazardous or pirimiphos methyl, which is also more expensive, can be used. The carbamates are also more expensive alternatives. The pyrethroids are normally used when resistance occurs to all other types of insecticide; they are among the safest such products currently available when applied at the recommended dosages. Vector control experts in the local health services or research institutes may be able to advise on locally effective pesticides.

Formulations

Insecticides are rarely applied in their pure form. They are available as special formulations, which are adapted to the requirements of the various application methods.

Residual insecticides for spray application are generally formulated as water-dispersible powders, emulsifiable concentrates or suspension concentrates.

Water-dispersible powder

This is a dry powder of insecticide mixed with a surface-active agent that allows the insecticide to dissolve in water. The insecticide remains in suspension in the water with occasional stirring.

The products are usually packaged as powders containing 5 - 80% active ingredient. One kilogram of a 75% powder formulation would consist of 250g of inert material and 750g of the pure insecticide. Such products are ready for mixing with water to form a spray suspension, normally containing 1 - 5% of active ingredient.

Emulsifiable concentrate

An emulsifiable concentrate consists of a solvent and an emulsifying agent in which the insecticide is dissolved. When mixed with water it forms a milky, white emulsion composed of finely suspended oil droplets. It remains in suspension with a minimum of agitation.

Suspension (or flowable) concentrate

A suspension concentrate consists of particles of the insecticide with a wetting agent and some water, which can be used to make a water-based suspension. A distinct advantage is that the ingredients are not flammable. The insecticide particles are larger and remain available on wall surfaces longer than those of emulsifiable concentrates. However, the particles are smaller than those of water-dispersible powders, and are therefore less effective on porous surfaces. The residues left on the wall are aesthetically more acceptable than those of water-dispersible powders. This type of formulation is available for several insecticides listed in Table 9.1.

Water-dispersible powder, emulsifiable concentrate or suspension concentrate?

For indoor spraying purposes, the water-dispersible powder is the most effective formulation in most countries. This is because it is most suited for porous surfaces such as brick and mud walls. The insecticide particles are comparatively large and absorption is comparatively slight. More active ingredient therefore remains available on walls to be picked up by resting mosquitos and crawling insects and the residual effect lasts longer.

The water-dispersible powder is also lighter and easier to transport than the emulsifiable concentrate. It can be prepacked for use in the field and is less toxic to humans.

The suspension concentrate is also suitable for rough surfaces, but special care is needed during the formulation process in order to avoid caking of solid materials at the bottoms of containers and, as it is a liquid, it requires relatively expensive containers and careful handling to avoid spillage.

The emulsifiable concentrate is more expensive and used for spraying impervious surfaces and walls with fine coverings because it does not cause spots and stains.

The residual effect of emulsifiable concentrates depends on the absorption capacity of the wall and on the physical properties of the insecticide. Usually, water-dispersible powders and suspension concentrates have a longer residual effect, except on non-absorbent surfaces where the effectiveness and persistence of the three kinds of formulation are equivalent.

Table 9.1 Insecticides used for residual wall-spraying

Insecticide	**Dosage (g/m^2)**	**Duration of effectiveness (months)**	**Insecticidal action**	**Safety class of active ingredient**[a]
Organochlorines				
DDT	1 - 2	6 or more	contact	MH

lindane	0.2 - 0.5	3 or more	contact	MH
Organophosphorus compounds				
malathion	1 - 2	1 - 3	contact	SH
fenitrothion	1 - 2	1 - 3 or more	contact, airborne	MH
pirimiphos methyl	1 - 2	2 - 3 or more	contact, airborne	SH
Carbamates				
bendiocarb	0.2 - 0.4	2 - 3	contact, airborne	MH
propoxur	1 - 2	2 - 3	contact, airborne	MH
Pyrethroids				
alphacypermethrin	0.03	2 - 3	contact	MH
cyfluthrin	0.025	3 - 5	contact	MH
cypermethrin	0.5	4 or more	contact	MH
deltamethrin	0.05	2 - 3 or more	contact	MH
lambdacyhalothrin	0.025 - 0.05	2 - 3	contact	MH
permethrin	0.5	2 - 3	contact, airborne	MH

[a] MH = moderately hazardous; SH = slightly hazardous.

Dosages and cycles

The dosage rate is the amount of insecticide applied to a unit of surface area. It is usually given in grams of insecticide per square metre (g/m^2). The optimal dosage rate may vary with place and season, with species of mosquito or other vector and with the material of the sprayed surface. Table 9.1 gives dosage rates which usually provide satisfactory results. Local vector control experts should advise on the most appropriate dosage rates.

The spray cycle is the time between consecutive insecticide spray rounds. In small communities where spraying can be done quickly, houses should be sprayed in the weeks preceding the onset of the transmission season. If this season lasts only three months an insecticide that persists for three months or more needs to be sprayed only once a year.

In areas where transmission occurs throughout the year, several spray cycles may be needed to cover the whole period. Residual effectiveness is normally extended when a relatively high dosage rate is used. A lower dosage can be applied when the transmission season is short.

Type of sprayed surface

The persistence of an insecticide sprayed on a surface varies not only with the type of insecticide and its formulation but also with the nature of the surface. Most insecticides last longer on wood and thatch than on mud. Mud surfaces absorb some insecticide, and certain types of mud may also break it down chemically. For example, malathion sprayed on wood may last three months or more, whereas on some mud surfaces it may last only three weeks.

If local data are not available, it is suggested that for spraying on wood or for short transmission periods the lower dosage rates given in Table 9.1 be chosen. The higher dosage rates may be used for applications on mud surfaces and where long persistence is needed. As discussed above, the persistence of an insecticide is also influenced by its formulation.

Commonly used insecticides

Organochlorines

Of this group of insecticides only DDT is discussed here in detail. Dieldrin was commonly used but, as it is highly toxic to humans and domestic animals, it is no longer available. Lindane has been used in areas where DDT resistance occurs. It is more toxic than DDT but can be applied safely when suitable precautions are taken. It is more expensive than DDT and less persistent, and consequently lindane spraying is rather costly. Because of resistance it is now of limited importance.

DDT

This was one of the first and most commonly used insecticides for residual spraying. Because of its low cost, high effectiveness, persistence and relative safety to humans it is still used for indoor wall spraying. However, the development of resistance and restrictions imposed in a number of countries have led to its replacement by other insecticides that are more expensive. A WHO Study Group met in November 1993 to consider the use of DDT for controlling vector-borne diseases. It concluded that it may be used for vector control, provided that certain conditions are met (*1*).

Commonly available formulations: 75% water-dispersible powder (the most commonly used) and 50% water-dispersible powder; 25% emulsion concentrate.

Dosage: 1 - 2g/m^2 depending on the surface (more on mud-bricks, less on timber) and the length of the transmission period (the higher dosage lasts longer).

Storage: it is stable and can be stored in tropical countries without deterioration if heat, bright sunlight and high humidity are avoided.

Residual effectiveness: six months or more.

The effectiveness and importance of DDT

The discovery of DDT in the 1940s led to a breakthrough in the control of malaria. The insecticide is highly effective in killing indoor-resting mosquitos when sprayed on house walls. It is cheap and remains effective over a period of many months. In many countries, malaria control programmes achieved substantial success because of the spraying of houses once or twice a year with DDT. However, in many areas the spraying could not be maintained because of the high cost of the operations and declining cooperation of the population. In addition, in many areas malaria mosquitos developed resistance to DDT, necessitating increased costs for more expensive replacement insecticides. Nevertheless, DDT is still an effective insecticide in a number of countries.

However, the use of DDT is increasingly being opposed by environmentalists who correctly point out that it is harmful when used for agricultural purposes. DDT does not break down quickly when sprayed on crops. It remains in the soil for a long time and can enter rivers and water supplies. Animals that eat insects poisoned with DDT or predators further up the food chain slowly become poisoned themselves. Humans eating contaminated vegetables and other products may also accumulate DDT in various tissues. In most countries this has resulted in a ban on the use of DDT.

This situation affects the availability and use of DDT for malaria control purposes. DDT is still one of the cheapest insecticides available (Table 9.2) and, if used for wall spraying, is relatively safe for humans and the environment. In spite of its widespread use in malaria control, there have been no reports of intoxication of humans as a result of wall spraying.

Organophosphorus compounds

This group of insecticides was developed after the organochlorines. Following the development of resistance to DDT the organophosphorus compounds became important as alternative residual insecticides. The most commonly used are malathion and fenitrothion. They are more costly than DDT and have a shorter residual effectiveness (Table 9.2).

Table 9.2 Cost comparison of insecticides as applied in residual spraying, excluding operational costs

Insecticide	Dosage (g/m^2) (technical grade)	Approximate duration of residual effect on mud (months)	Number of applications (6-month period)	Total dosage per 6-month period (g/m^2)	Formulation[a]	Total amount of formulation per m^2 per 6-month period	Approximate cost/tonne[b] (US$)	Cost/m^2 (US cents per 6-month period)	Cost ratio (DDT = 1)
DDT	2	6	1	2	75% WDP	2.67	3000	0.8	1
malathion	2	3	2	4	50% WDP	8	2100	1.68	2.1
fenitrothion	2	3	2	4	50% EC	8	7500	6	7.5
propoxur	2	3	2	4	20% EC	20	9300	18.6	23.25
deltamethrin	0.025	6	1	0.025	2.5% WDP	1	25000-28000	2.5	3.125
permethrin	0.125	3	2	0.250	25% WDP	1	30000	3	3.75

[a] WDP: water-dispersible powder; EC: emulsifiable concentrate.
[b] Excluding freight costs.
Source: *2*.

Malathion

This has become one of the most commonly used residual insecticides, following the development of resistance to DDT in many countries. It is classified as slightly hazardous. The absorption of particles by spray workers through inhalation, ingestion or contact with the skin reduces the activity of the enzyme cholinesterase in the nervous tissue. Signs of severe poisoning are muscle twitching and weakness followed by fits and convulsions. Spray personnel should not work with malathion for more than five hours a day, nor for more than five days a week. If the insecticide is stored for long periods in hot areas, impurities may develop which make the product more toxic to humans. Malathion is the least expensive organophosphorus insecticide and the safest when manufactured according to WHO specifications. It is commonly used as a residual spray in the control of malaria and Chagas disease. Acceptability to house owners is sometimes a problem because of its unpleasant smell.

Commonly available formulations: 50% water-dispersible powder and 50% emulsifiable concentrate.

Dosage: 1 or 2g/m^2.

Residual effectiveness: at the higher dose it may last up to six months on thatch or wood but only 1 - 3 months on mud and plaster surfaces. Mud surfaces with a high alkali content (minerals) tend to break down the malathion most rapidly.

Fenitrothion

Fenitrothion is classified as moderately hazardous and is more toxic than malathion to humans. Spray personnel and workers handling the insecticide must observe strict precautionary measures. As with malathion, repeated exposure may lead to a reduction of cholinesterase in the nervous tissue. Spray personnel should be monitored regularly for blood cholinesterase activity; if the level is low they should stop spraying until it has returned to normal. Fenitrothion is a contact poison but it also has an airborne toxic effect on insects which may last up to two months after spraying. The airborne effect may be useful where target mosquitos bite but do not rest in houses. It is often effective against pests that have developed resistance to malathion.

Commonly available formulations: 40% and 50% water-dispersible powder; 5% emulsifiable concentrate.

Dosage: 1 or 2g/m^2.

Residual effectiveness: on wood surfaces, 1g/m^2 may remain effective for up to 2.5 months; on mud surfaces it lasts 1 - 2 months.

Carbamates

Propoxur

This product is classified as moderately hazardous. If absorbed it reduces cholinesterase activity, which, however, returns quickly to normal once exposure ceases. It is fairly toxic to fish, birds, bees, livestock and wild animals. Propoxur has an airborne effect inside and near houses for up to two months after spraying. It is used in areas where resistance occurs to organochlorine and organophospho- rus insecticides.

Commonly available formulations: 50% water-dispersible powder and 20% emulsifiable concentrate.

Dosage: 1 or 2g/m^2.

Residual effectiveness: at 2g/m^2 it may last 2 - 3 months.

Bendiocarb

Bendiocarb is classified as moderately hazardous. It is rapidly metabolized after absorption, and metabolites are totally excreted from the body within 24 hours. It inhibits cholinesterase, but recovery is very rapid once exposure ceases. When used with appropriate safety precautions, it is safe for operators, householders and livestock, but ducks are particularly susceptible.

Commonly available formulation: 80% water-dispersible powder in preweighed sachets, one sachet to be used per spray charge.

Dosage: 0.2 - 0.4g/m^2.

Residual effectiveness: remains effective for 2 - 3 months.

Synthetic pyrethroids

This group includes the most recently developed residual insecticides. The compounds that have been tested for wall-spraying are permethrin, deltamethrin, lambdacyhalothrin, cypermethrin and cyfluthrin. They are used where resistance occurs against the previous groups of insecticides. The pyrethroids are moderately hazardous and under normal conditions of use they are safe for spray personnel and house owners.

Deltamethrin: available as 2.5% and 5.0% water-dispersible powder and as 2.5% and 5.0% emulsifiable concentrate. At a dosage of 0.05g/m^2 it usually remains effective for 2 - 3 months on mud and thatch surfaces, but nine months has been reported for other surfaces.

Permethrin is available as 25% water-dispersible powder. At a dosage of 0.5g/m^2 it remains effective for 2 - 3 months.

Lambdacyhalothrin is available as 2.5% emulsifiable concentrate and as 10% wettable powder in preweighed sachets. At a dosage of 0.025 - 0.05g/m^2 it may remain effective for 2 - 3 months.

Cypermethrin is available as 5% and 25% emulsifiable concentrate. At a dosage of 0.5g/m^2 it may remain effective for four months or longer.

Preparation of insecticide suspension

If the standard spraying procedure (see p. 376) is adopted the spray liquid will be applied at a rate of 40ml per m^2 or one litre per $25m^2$. This amount of suspension normally stays on the surface without run-off.

Water-dispersible powder

One litre of spray suspension can be prepared using the following formula:

$$X = \frac{25 \times Y}{C} \times 100$$

where:

X = weight of water-dispersible powder required (g)
Y = recommended application rate (g/m^2)
C = concentration of active ingredient in formulation (%).

Example

DDT (75% water-dispersible powder) is to be sprayed at a dosage of $2g/m^2$.

$$X = \frac{25 \times 2}{75} \times 100 = 66.6g$$

For an eight-litre tank, the amount of water-dispersible powder needed is:

$$8 \times 66.6 = 533.3g$$

The insecticide should be packed in small bags containing 533.3g each. In the field, put water in a mixing bucket until the eight-litre mark is reached. Mix the contents of one bag with the water, using a wooden paddle. Pour the solution into the sprayer through a funnel with a screen, close the tank and shake it.

Emulsifiable concentrate

To prepare an insecticide suspension from an emulsifiable concentrate, use the same formula as for the water-dispersible powder, with:

X = amount of emulsifiable concentrate needed (ml)
Y = recommended application rate (g/m^2)
C = concentration of active ingredient in formulation (%).

To prepare one litre of suspension, add *X* ml of emulsifiable concentrate to (1000 - *X*) ml of water.

Example

DDT (25% emulsifiable concentrate) is to be sprayed at a dosage of $1 g/m^2$.

$$X = \frac{25 \times 1}{25} \times 100 = 100 ml$$

To prepare one litre of suspension, add 100ml of emulsifiable concentrate to 900ml of water. For an eight-litre tank, add 800ml of emulsifiable concentrate to 7200ml of water.

Manually operated sprayers

There are many different types of hand-operated sprayer. Most models are used for the control of agricultural pests. With some adaptations such sprayers may also be suitable for use in public health and for household pest control. The World Health Organization has produced detailed specifications of spraying equipment suitable for residual wall-spraying in order to ensure uniform and safe application of insecticides (*3*).

Types of hand-operated sprayer

Compression sprayer

Usually considered the standard equipment for residual spraying. However, many models are available and only a few comply with WHO specifications, which are discussed further in the text.

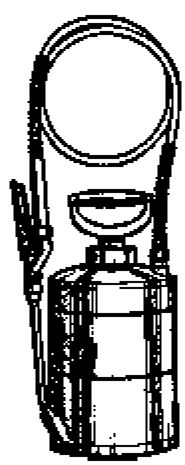


Fig. 9.1 A hand-compression sprayer (© WHO).

Knapsack sprayer

Widely used in agriculture, this is carried on the back. A frame or shield prevents contact between the tank and the back. It is a continuous type of sprayer with a fairly constant discharge rate. The person maintains pressure in the tank by pumping air with a lever with one hand and directs the spray lance with the other. If the sprayer is fitted with a spray control valve, continuous pumping may not be necessary. The knapsack sprayer can be used for spraying breeding sites with larvicides but should not be used for residual wall-spraying.

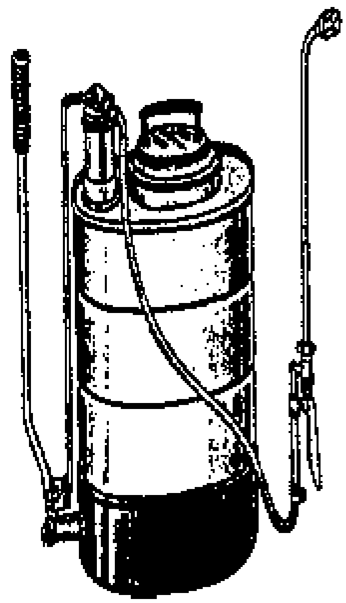
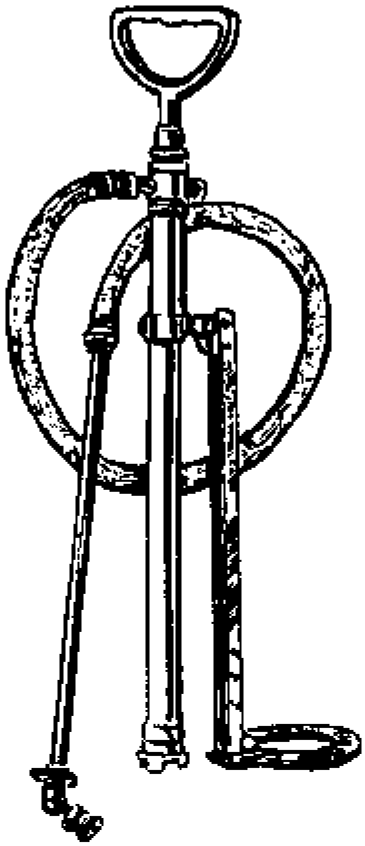


Fig. 9.2 A knapsack sprayer (© WHO).

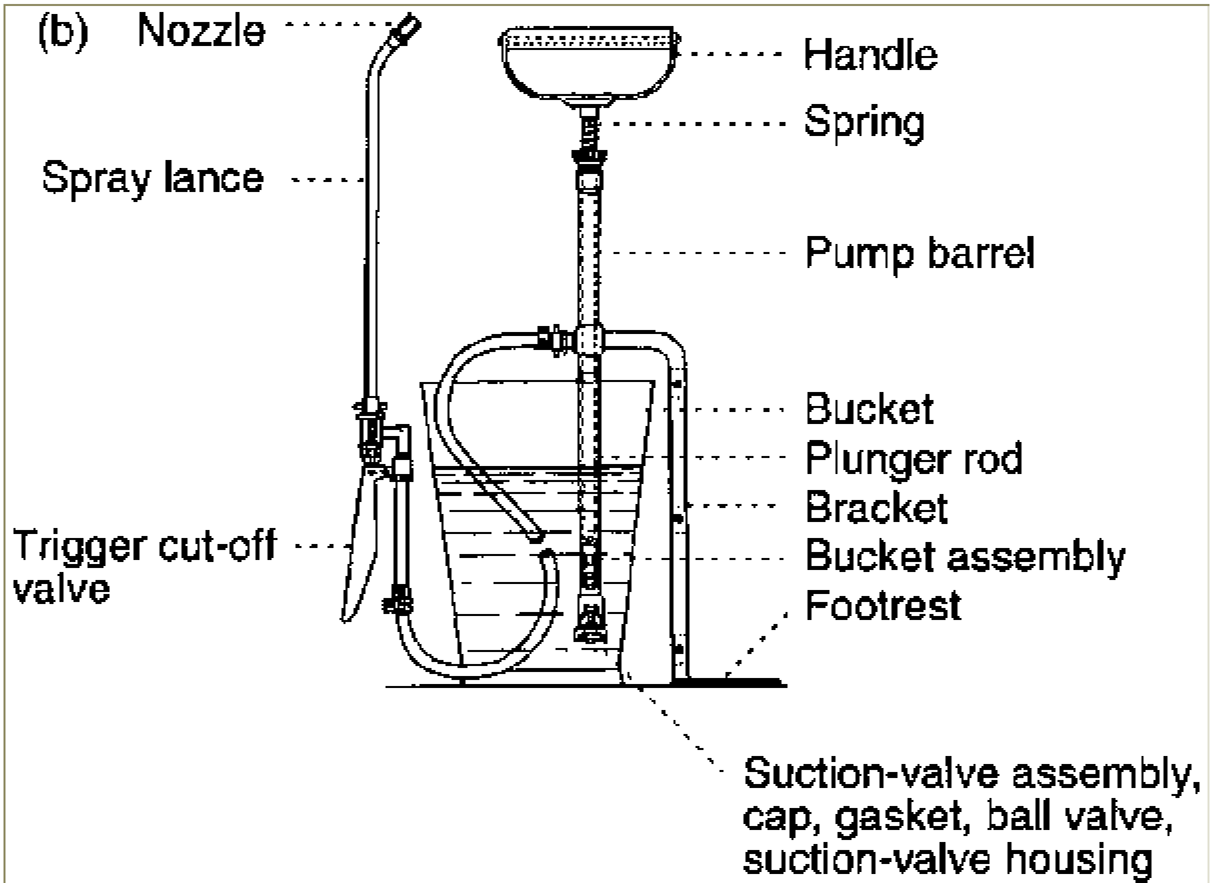
Stirrup pumps

These are used in some vector control programmes because they are less costly than compression sprayers. The pump, mounted on a footrest or stirrup, is inserted in the spray liquid in a bucket. A hose attached to the pump leads to the spray lance. Two persons are needed, one to pump and one to direct the spray. The pressure varies with the speed of pumping, and so it is difficult to make uniform spray applications. Because of their inaccuracy and because of the risk of spilling insecticide from the open bucket inside houses, stirrup pumps are not recommended. They should not be used with hazardous pesticides.

Fig. 9.3 A stirrup pump.



(a) © L. Robertson



(b) © WHO

Compression sprayers

Functioning and design

A hand-compression sprayer basically consists of a tank for holding a liquid insecticide formulation, which can be pressurized by means of a hand pump attached to it. The compressed air forces the liquid from the tank via a hose with a cut-off valve, a lance and a nozzle (Fig. 9.4).

Tank assembly (Fig. 9.5)

- **The tank** itself is usually made of stainless steel. Most tanks have four openings on top: a large one for filling, fitted with a removable cover; and openings for the air pump, discharge system and pressure gauge.

- **The tank cover** (Fig. 9.6) consists of: (1) a rubber gasket; (2) a handle; (3) a pressure-release valve, operated by hand or by giving the handle a quarter turn; (4) a chain to prevent the cover from being lost.

- **An air pressure gauge** is used to measure pressure in the tank.

• **The shoulder strap** should be wide enough to prevent it from cutting into the shoulder of the person using the sprayer. It is fastened to the tank with steel buckles. On large tanks it is adjustable.

• When the tank is not in use, the spray lance is held in a **bracket** and **nozzle cup**, which protects the nozzle from damage.

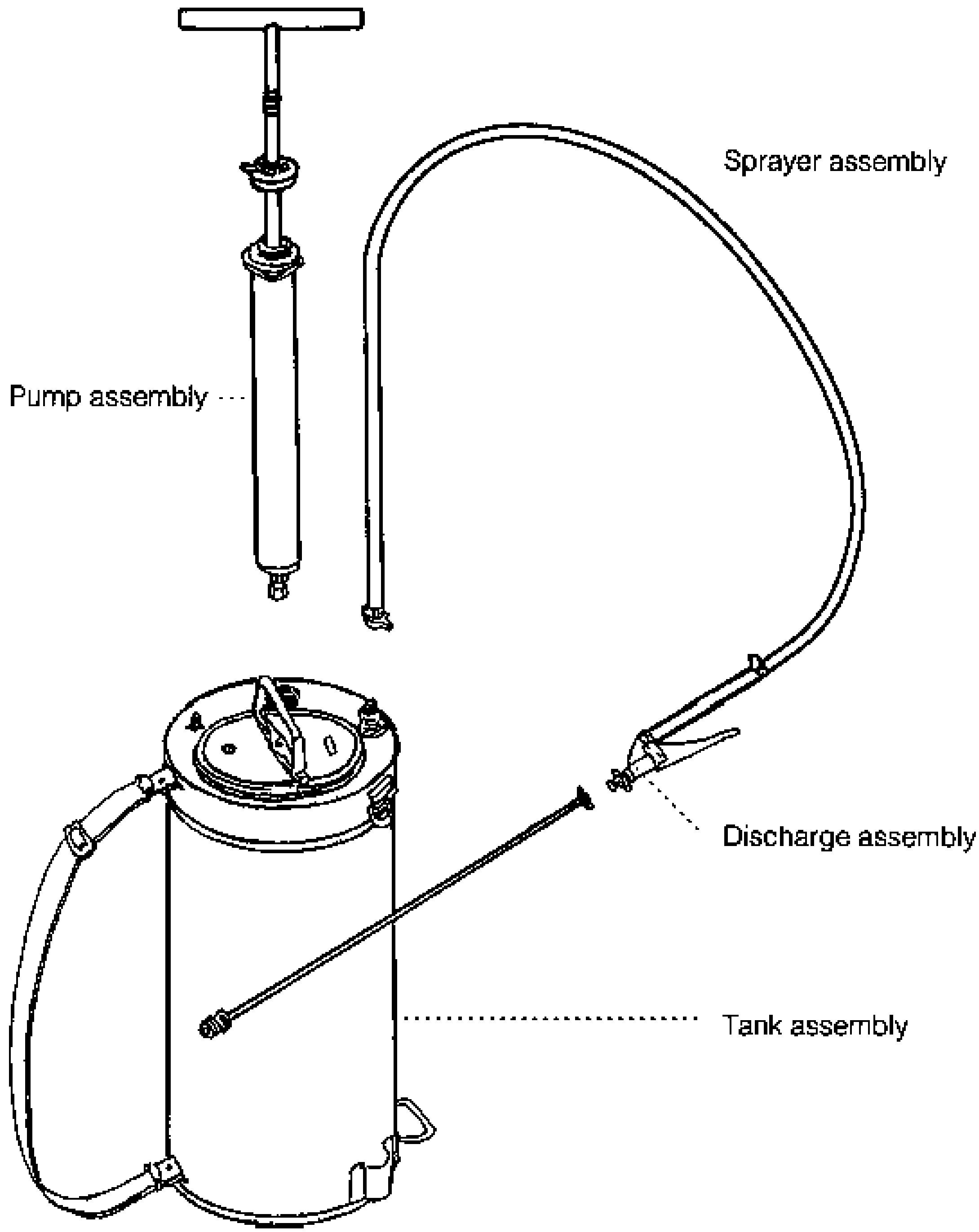


Fig. 9.4 Main components of a hand-compression sprayer (© WHO).

Air pump assembly (Fig. 9.7)

A piston-type pump consists of a plunger operated inside a cylinder. The plunger forces air through a valve at the base of the cylinder. The plunger seal may be made of leather, rubber or plastic, and must be resistant to the chemicals used in insecticide formulations.

Discharge assembly

The main parts are: (1) the dip tube, mounted in the tank with an O-ring gasket; if the gasket is damaged, air may leak from the tank; (2) a flexible hose of a material resistant to chemicals used in pesticide formulations; (3) a filter with housing which filters out particles too large to pass through the nozzle opening; it can be taken out for cleaning or replacement; (4) a cut-off valve that permits the person using the sprayer to close the system; (5) a lance, or extension tube, 40 - 60cm in length; some models are telescopic; (6) a nozzle assembly, comprising a nozzle tip, filter, body and cap; the tip may be of stainless steel, ceramic or plastic (Fig. 9.8). The nozzle tip is the most important part of the sprayer. It should deliver a precise amount of spray suspension per minute at a certain pressure in the tank, and maintain a uniform spray pattern and swath width. The selection of the nozzle depends on how the insecticide is to be sprayed.

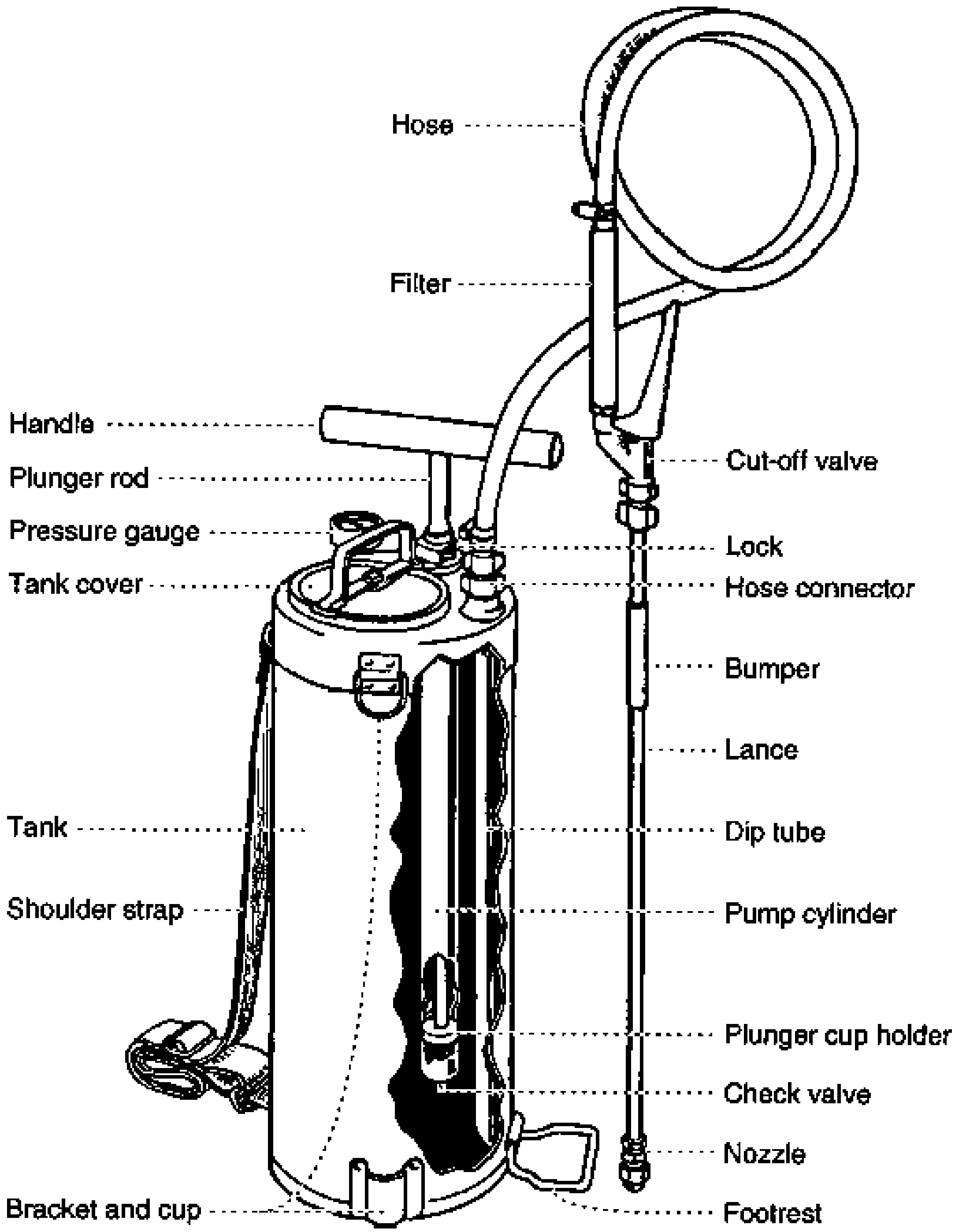


Fig. 9.5 Cutaway diagram of a hand-compression sprayer (© WHO).

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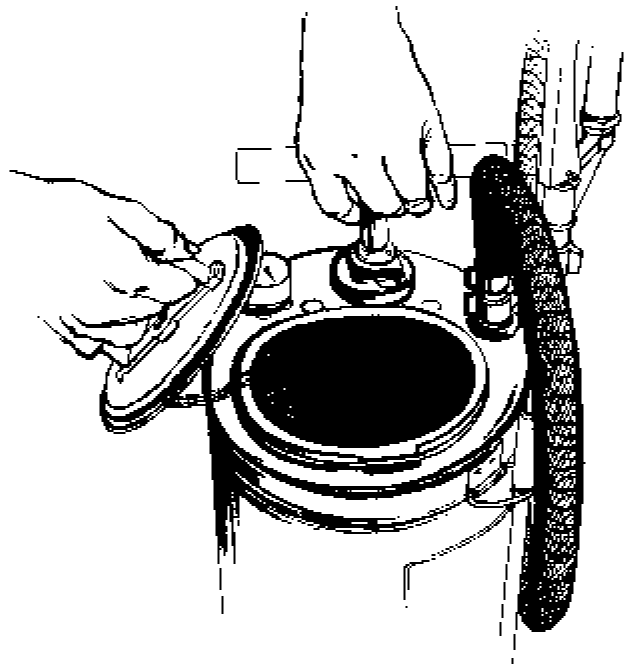

Fig. 9.6 Close-up of upper part of tank with tank cover removed.

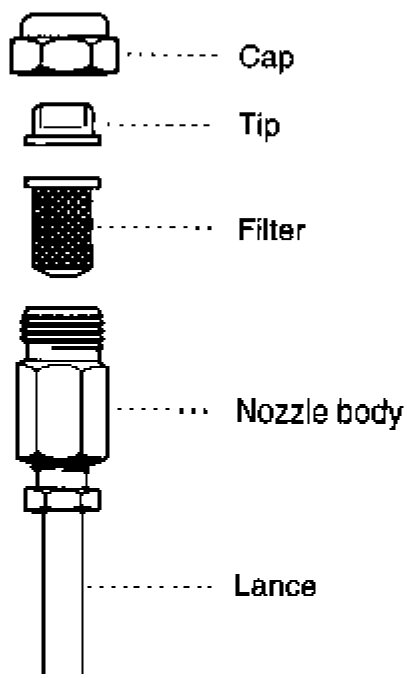

Fig. 9.7 Cutaway diagram of an air pump assembly (© WHO).

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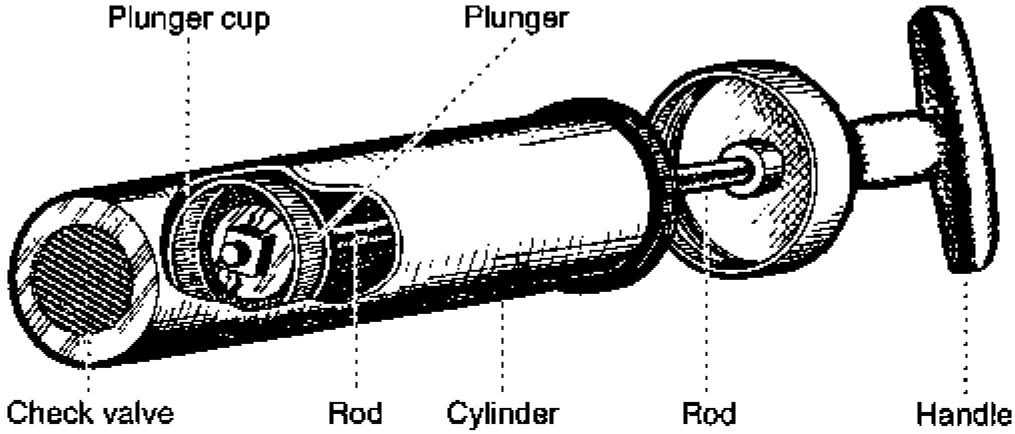

Fig. 9.8 Parts of a nozzle (© WHO).

Types of nozzle (Fig. 9.9)

- The solid or jetstream nozzle is used to treat cracks and crevices for control of bedbugs, soft ticks, cockroaches and ants.
- The flat-spray nozzle delivers a fan-shaped spray, and is preferred for residual wall-spraying.
- The hollow-cone nozzle is used to spray breeding sites of mosquitos and tick and mite habitats in vegetation.
- The solid-cone nozzle is used to spray mosquito breeding sites.

The flat-spray nozzle commonly used for wall-spraying produces a spray with an angle of 80° and 757ml per minute at a standard tank pressure of 280kPa. It is usually made of specially hardened stainless steel. The nozzle tip is designed with flat surfaces on either side of the orifice so that it can be removed easily.

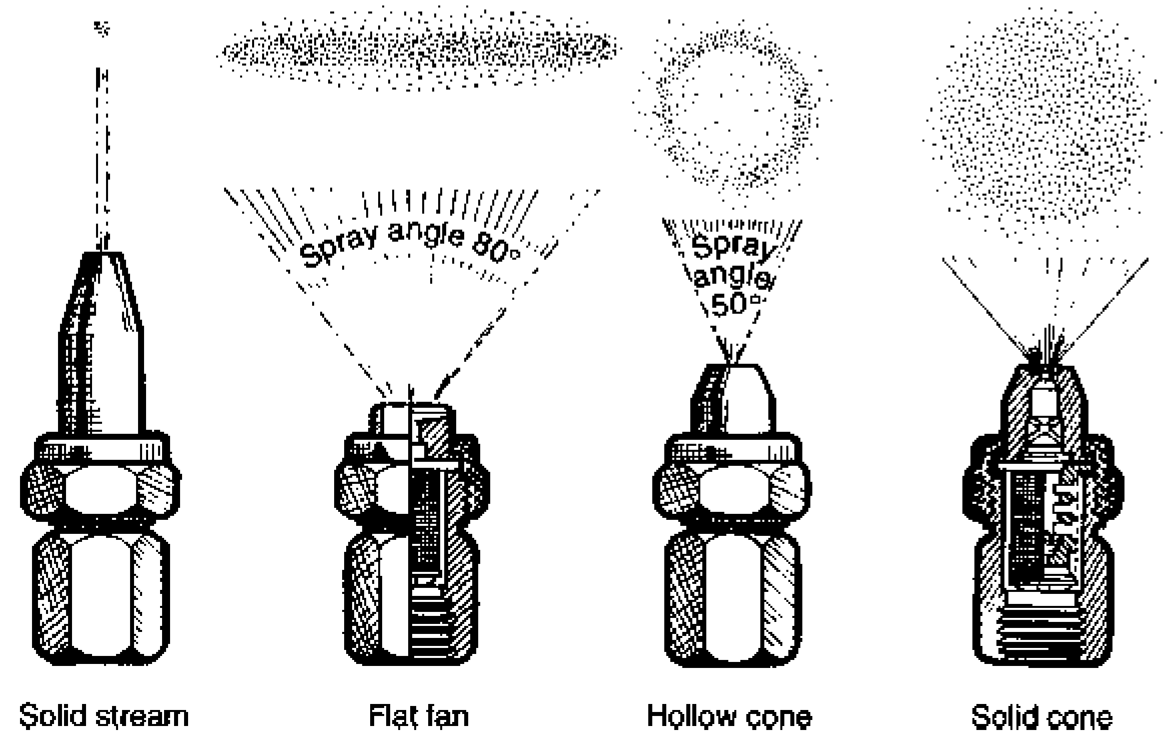

Fig. 9.9 Types of nozzle (© WHO).

Use and operation of a hand-compression sprayer

Preparation and addition of pesticide

Pesticides should be carefully handled. Water-dispersible powders should be packaged at a central point before spray operations are started. The correct amount of insecticide should be put into a suitably sized plastic or paper bag (see p. 366 for calculation of insecticide dosage). The people who do this should wear protective clothing (see p. 383). The risks of contamination of personnel, spillage and wastage in the field are thus reduced, as is the workload during spraying activities. Accurate dosing of insecticide is also made easier. Bags and insecticide containers should be disposed of safely after use (see Chapter 10, p. 385).

Mixing

Before the insecticide is mixed, the sprayer should be checked and calibrated with water. In the field, a wooden paddle or stick should be used to mix water-dispersible powders with a small quantity of water to form a smooth paste. This is added to the sprayer tank. More water is used to rinse out the mixing container, the wash is poured into the sprayer tank up to the level required, and stirring is repeated. The mixing container should now be clean. House owners can assist spray personnel by providing water (Fig. 9.10).

Filling

The suspension is poured into the spray tank through a strainer or filter funnel to prevent dirt from entering (Fig. 9.11). If the suspension is not filtered the nozzle tip may become blocked during spraying.

Fig. 9.10. Mixing the insecticide solution.

Fig. 9.11. Filling the spray tank.

The tank should not be more than three-quarters full. The remaining space should be left for the compressed air. The tank usually has a mark indicating the required amount; for standard sprayers this is 8 or 10 litres.

Shaking

The suspension is kept well mixed by shaking the tank before beginning to spray and from time to time during spraying. This is done by grasping the sprayer by the pump shaft and the bottom end of the tank. The tank should not be held by the strap, nor should it be swung forward and backward while on the shoulder. Formulations that meet WHO specifications should remain in suspension without extra shaking.

If preweighed pesticide sachets are used, the required amount of water should be poured directly into the sprayer. The contents of the sachet should be added, the sprayer closed, and the contents mixed by turning the sprayer upside down.

Preparation of sprayer

- **To close the tank**: insert the cover vertically into the tank, lift it and fit it into the tank opening; turn the handle across the width of the opening.

- **To open the tank**: push down the air-release valve by turning the handle on the cover; the cover will become loose once the air is at atmospheric pressure.

Pressurizing the tank

Put a foot on the foot rest (if available) and unlock the pump plunger. Pull the plunger all the way up with both hands and then push it downwards (Fig. 9.12). Use full, even strokes.

If the sprayer has a pressure gauge, keep pumping until it registers a pressure of about 380kPa (55psi). If the gauge is inaccurate, assume that a full stroke of the pump will provide 1psi, so normally use 55 full strokes when pressurizing a tank that is three-quarters full. The upper and lower limits for the working pressure are about 380kPa (55psi) and 170kPa (25psi), giving an average pressure during spraying of about 280kPa (40psi).

During spraying, pressure has to be maintained by occasional repumping. Try to get accustomed to the number of pumping strokes required to reach the maximum pressure in case the pressure gauge stops working. Keep the plunger shaft in place with the locking lever. Always release the pressure when the sprayer is not in use or when it is being transported.

Fig. 9.12. Pressurizing the spray tank.

Application of spray

The insectide suspension has to be sprayed evenly at the recommended dosage over all sprayable surfaces. The following factors determine how much insecticide is sprayed on a surface:

- the concentration of insecticide in the suspension (calculation of the dosage is discussed on p. 366);

- the air pressure in the sprayer (maintain at 170 - 380kPa (25 - 55psi));

- the nozzle tip aperture size;

- the distance from the nozzle tip to the surface being sprayed;

- the speed of application over the surface.

Training

The two latter factors imply skill and training, and spray personnel should be trained to spray at the proper rate to cover 19m^2 per minute. The wall of a building can be used for practice. Mark an area 3m high and 6.35m long, divided into nine bands, the first one 75cm wide and the remainder 70cm wide (Fig. 9.13).

The spray nozzle will produce a swath 75cm wide if kept at a distance of 45cm from the wall (Figs 9.14 and 9.15). To practise keeping the nozzle 45cm from the wall, fit a wooden stick or other extension to the lance with rubber bands or string. Make sure the length from the nozzle tip is 45cm. Extend the right arm and incline the body towards the surface while raising or lowering the right arm so that the end of the stick remains in contact with the surface.

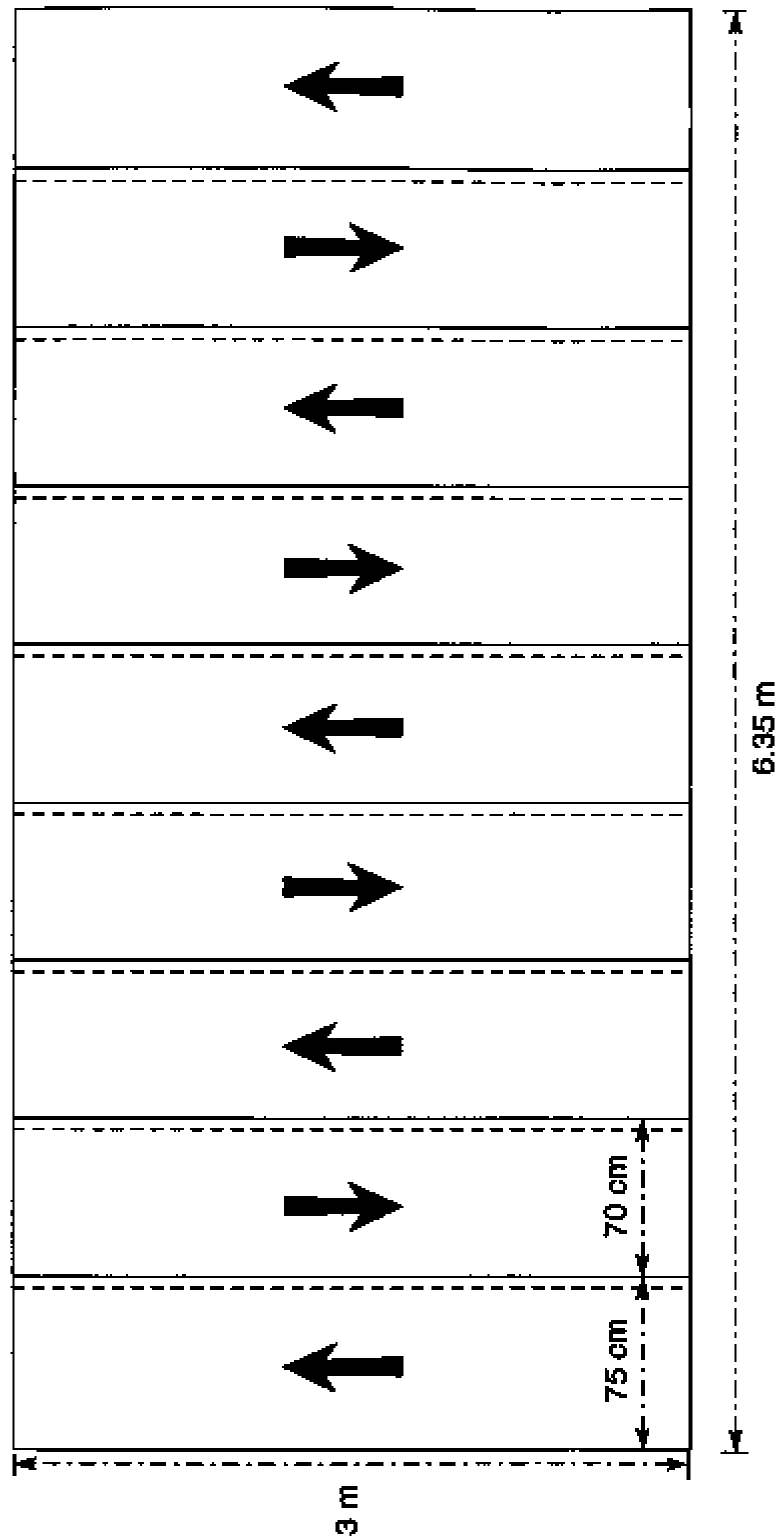

Fig. 9.13. Training board for residual spraying which can be marked with chalk on the wall of a large building (© WHO).

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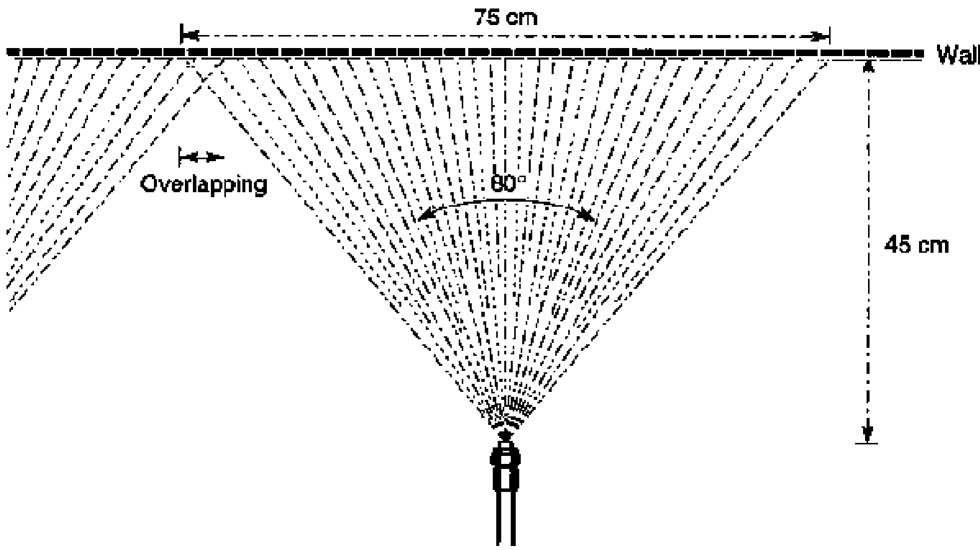

Fig. 9.14. Nozzle discharge pattern (© WHO).

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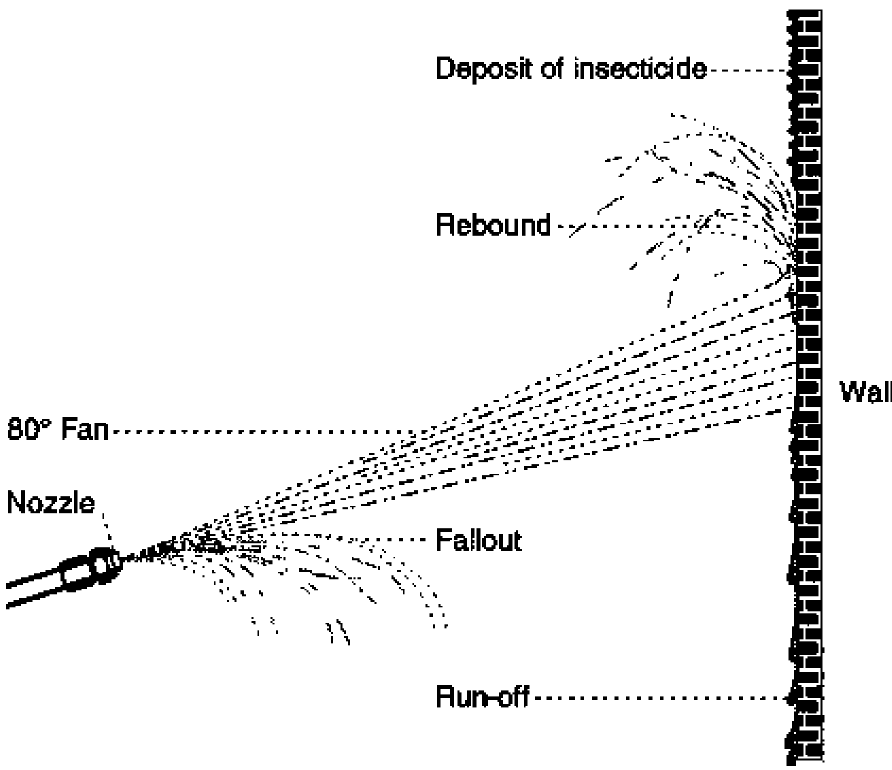

Fig. 9.15. When a vertical surface is sprayed, some of the insecticide particles bounce off into the air; a heavy application results in insecticide run-off down the wall (© WHO).

WHO 96719

The spray worker stands directly in front of the wall. If the spray worker is right-handed, the sprayer is carried on the left shoulder and held in place with the left hand; the spray lance is held in the right hand (Fig. 9.16). A helmet or hat and other protective clothing should be worn.

Starting at a bottom corner of the wall and spraying at a uniform rate, move upwards to the top. Continuing to spray, take one step to the right. The next swath should overlap with the previous one by about 5cm (Fig. 9.13). Spray down to the bottom. Continue in this way until the entire area of $19m^2$ is covered. Each swath of 3m in height should be covered in 6.7 seconds so that nine swaths take a minute. The speed can be controlled by counting the seconds aloud or by using a stopwatch.

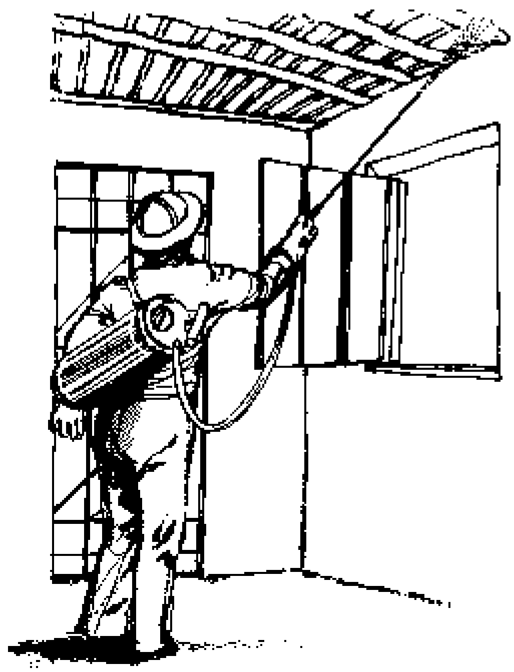

Fig. 9.16. Correct attitude and protective clothing for wall-spraying.

If no suitable wall surface is available, an area 1.80m high and 6.35m long ($11.43m^2$) can be used for practice. The area should be divided into nine bands, as described above. Each swath of 1.80 m in height should be covered in 4 seconds so that nine swaths take 36 seconds.

Maintenance and repair

Spare parts

Most sprayers are provided with an illustrated manual giving:

- a description of the equipment;
- operating instructions;
- maintenance instructions;
- information on how to solve problems;
- a list of spare parts.

Spare parts should always be available, especially gaskets and valves. When ordering from the manufacturer or a local supplier, give the sprayer model, the part name and the identification number.

Cleaning

Clean the tank daily after spraying. Do not let pesticide remain in it after use. Rinse the sprayer thoroughly with water and then allow to dry. Do not discard the water in a stream, pond or place where it can be reached by humans or animals; a pit latrine or a hole in dry ground, away from water collection points, rivers, ponds or agricultural land, is the best place for disposal.

Remove, rinse and clean the filter assembly at the control valve. Remove the filter from the valve by grasping it at its base, not by its screen. Twist it slightly on pulling it out (Fig. 9.17).

Reassemble all clean parts except the nozzle. Put clean water in the tank, seal the tank and pump air into it. Open the control valve and let the water flow from the lance to flush the hose, filters, control valve and lance. Remove the tank cover and dry the inside of the tank.

Clean the nozzle tip by washing thoroughly with water (Fig. 9.18). Use a pump to blow air through the orifice, then clean and dry it. Remove any dirt from the orifice with a fine bristle from a brush or with a toothpick; never use metal wire. Dirt can also be blown out by pushing the nozzle against the pressure release valve on top of the tank cover.

Maintenance

Inspect the tank at regular intervals, and replace any worn or damaged part. Inspect the lip of the pump cylinder for cracks that could cause the tank to lose pressure. Check the rubber hose for cracks and weak spots. After some time the hose becomes weakened near the point of attachment to the spray-can or cut-off valve. The weak part should then be cut off and the hose remounted. Put a few drops of clean oil on the plunger cup leather to keep the pump cylinder lubricated and to ensure sufficient pressure. Replace the leather if damaged.

Nozzle tips erode during spraying. They should be replaced when worn. An eroded orifice causes an increase in the amount of pesticide delivered. The discharge rate should be measured from time to time by qualified personnel. A simple method is to spray a suspension on to a dark surface: irregularities in the swath indicate that the nozzle tip needs to be replaced.

Fig. 9.17. Removing the spray filter for cleaning (© WHO).

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Fig. 9.18. Clean the nozzle tip with water (© WHO).

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Storage

Check that the tank is empty, put the parts back together and store the tank upside down with the cover lying loosely inside the tank and the plunger locked (Fig. 9.19). Make sure the lance and nozzle cannot fall or be otherwise damaged. Store the cut-off valve locked open.

Problem-solving

• *Pumping does not build up pressure*. Most probably the plunger cup leather is dry or damaged. Apply oil or replace.

• *The sprayer does not spray or sprays irregularly while under pressure*. Release pressure and clean the nozzle (see p. 379). Also check the filter at the spray control valve. Clean if necessary.

• *The sprayer does not maintain pressure; air leaks out*. Check the tank cover gasket and the pump cylinder gasket for leaks. Clean the seating surfaces and replace the gaskets if necessary. If air leaks are difficult to locate, cover fittings with a soapy solution and watch for air bubbles.

• *The sprayer does not shut off*. Release pressure, and disassemble the cut-off valve as indicated in the pump manual. Clean, check and if necessary replace the valve seat, O-ring, spacer, washer and valve-pin packing.

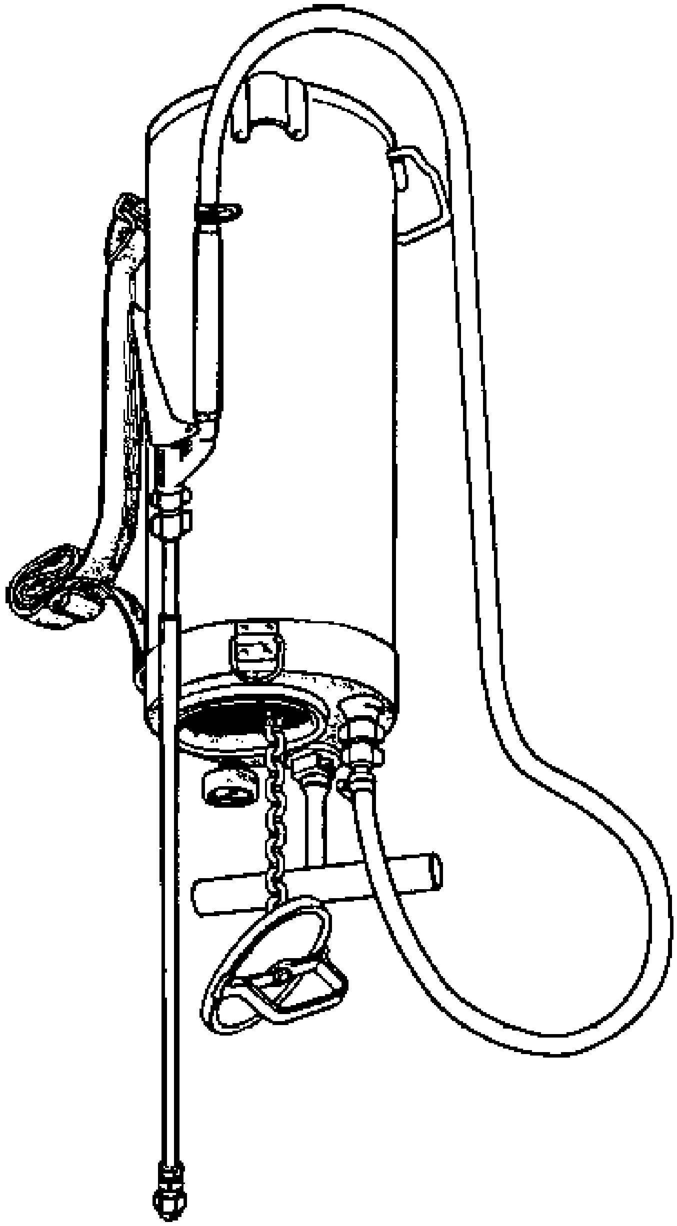

Fig. 9.19. Store the tank dry and upside down (© WHO).

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Spraying operations

Where to spray

All known resting or hiding places of the target insect have to be sprayed. Depending on the species, target insects may rest in human dwellings, unoccupied houses, animal shelters, food stores and kitchens. The decision on where to spray should be taken only after consulting an expert on vector control.

Experts also have to indicate whether shops, schools, churches, factories, warehouses and other large buildings in which people do not regularly sleep should be sprayed. In case of doubt such buildings should not be sprayed because of the expense.

In principle, all potential indoor resting surfaces should be sprayed. However, it may be too time-consuming or unacceptable to spray some surfaces, such as under furniture and mats, behind pictures, roof trusses, beams and pillars. It is usually sufficient to limit spraying to walls, ceilings and under eaves.

Selective spraying

Some target insects are known to have special preferences for indoor resting surfaces. For example, some mosquito species rest mainly at the bases of walls, or only on ceilings or under eaves. Spraying only these surfaces will then provide effective control at the lowest possible cost.

In malaria control it is often not necessary to spray buildings in which humans do not regularly sleep. However, temporary shelters used during the planting or harvesting season or for hunting or fishing should be sprayed.

For the control of Chagas disease it may be necessary in some areas to spray not only houses but also peridomestic hiding places for triatomine bugs in animal shelters and food stores.

When to spray

In areas where mosquitos seasonally transmit malaria or other diseases insecticides should be applied just prior to the onset of transmission. This is particularly important when the insecticides used give protection for only a few months. Large programmes may have difficulty in timing spraying properly because of the need to spread the spraying operations equally over the year. In such circumstances, priority should be given to proper timing of spraying in the localities known to have most cases of malaria. This problem does not arise if spraying is organized at community level.

Planning of spraying should take into account the behaviour and customs of the people. Spraying should be carried out when people are expected to be at home. Temporary structures in the field used during the harvesting or planting season should be sprayed shortly after their construction. The timing and frequency of spray rounds may also be influenced by the replastering of walls during certain cultural events.

Planning a spray programme

Individuals can spray their own houses but spraying is generally carried out to control a disease affecting a whole community. Regional or national disease control programmes may be responsible for the spraying of all houses in large areas. Such large-scale operations require detailed plans defining the boundaries of the areas to be sprayed, the methods and procedures of house-spraying, the duration of the programmes, requirements for personnel, supplies and equipment, and the preparation of budgets.

A spraying programme is much simpler to organize for a single community. The following points may then be considered.

• **Effectiveness of method**. Evidence should be provided by the local health authorities that spraying is an effective and locally appropriate method. This should include information on the target insect, its behaviour and its susceptibility to different insecticides.

• **Informing the community**. Community leaders or the local health services should educate community members on the need for a spraying programme and on the responsibility of each community member to collaborate. The agreement of the community has to be sought.

The community has to be told:

- how the insecticide works and what protective effect it will have;

- that the insecticide is safe to the inhabitants;

- that walls, ceilings and furniture will not be damaged;

- that house owners should protect any object they do not want to be sprayed. The inhabitants should cooperate by preparing their houses; furniture, cooking utensils and food should be removed before spraying is carried out; they can be placed outdoors or covered with a sheet of plastic and put in the centre of a room;

- that house owners should not replaster or wash sprayed walls for a few months after spraying.

• **Estimation of quantity of supplies needed**. These include insecticides, spray pumps, spare parts, protective clothing, gloves, soap and plastic sheets to cover furniture.

Measuring total surface area to be sprayed

It is preferable to start by making a map of the community, indicating the location of all the houses to be sprayed. Each house should be given a reference number, which is marked on the map and painted on the house.

The approximate size and type of each house should be indicated as well as the kind of material used for walls, ceilings and other sprayable surfaces.

If the houses are of similar construction and design, an estimate can be made of the average sprayable surface area per house. A sample of about five houses out of every 100 should be sufficient. The walls, ceilings and other sprayable surfaces in these houses are measured; this can be done with a stick about two metres long which is marked at half-metre intervals.

Calculation of amount of insecticide needed for one round of spraying

The total amount of insecticide (T) needed depends on:

N: the number of houses
S: the average sprayable surface per house (m^2)
Y: the target dosage of insecticide (g/m^2)
C: the concentration of active ingredient in the formulation (%)

$$T = \frac{N \times S \times Y}{C} \times 100$$

Example

A village has 100 houses. The average surface that can be sprayed per house is $200m^2$. The recommended dosage of DDT is $2g/m^2$. The DDT is available as a 75% water-dispersible powder.

$$T = \frac{100 \times 200 \times 2}{75} \times 100 = 53.3kg$$ of DDT (75% water-dispersible powder) 75

It is recommended that at least 10% extra insecticide be held in reserve.

Personnel and equipment required

One person can spray about 8 - 10 houses a day when working full time. In a community of 200 houses two persons equipped with one spray pump each can spray all the houses in about two weeks. When purchasing the sprayers an adequate supply of the spare parts most likely to be needed should be obtained. It can be assumed that a nozzle tip will have to be replaced after spraying 200 houses. The cost of spare parts can be estimated at 10% of the cost of the sprayers.

The spray workers should be provided with protective clothing and soap (see Chapter 10). A pair of gloves, an apron, a mask and goggles (glasses) are needed for the person who preweighs and packs the insecticide in small bags for later use.

One person, perhaps a community leader or health worker, should supervise spraying operations.

References

1. *Vector control for malaria and other mosquito-borne diseases. Report of a WHO Study Group.* Geneva, World Health Organization, 1995 (WHO Technical Report Series, No. 857), Annex 1.

2. *Control of the leishmaniases. Report of a WHO Expert Committee*. Geneva, World Health Organization, 1990 (WHO Technical Report Series, No. 793).

3. *Equipment for vector control*, 3rd ed. Geneva, World Health Organization, 1990.

Selected further reading

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Chemistry and specifications of pesticides. Eighth report of the WHO Expert Committee on Vector Biology and Control. Geneva, World Health Organization, 1984 (WHO Technical Report Series, No. 699).

Vector resistance to pesticides. *Fifteenth report of the WHO Expert Committee on Vector Biology and Control*. Geneva, World Health Organization, 1992 (WHO Technical Report Series, No. 818).

Chapter 10 - Safe use of pesticides

Pesticides are toxic to both pests and humans. However, they need not be hazardous to humans and non-target animal species if suitable precautions are taken. Most pesticides will cause adverse effects if intentionally or accidentally ingested or if they are in contact with the skin for a long time. Pesticide particles may be inhaled with the air while they are being sprayed. An additional risk is the contamination of drinking-water, food or soil.

Special precautions must be taken during transport, storage and handling. Spray equipment should be regularly cleaned and maintained to prevent leaks. People who work with pesticides should receive proper training in their safe use.

Precautions

The label

Pesticides should be packed and labelled according to WHO specifications (*1*). The label should be in English and in the local language, and should indicate the contents, safety instructions (warnings) and possible measures in the event of swallowing or contamination. Always keep pesticides in their original containers (Figs. 10.1 and 10.2). Take safety measures and wear protective clothing as recommended.

Storage and transport

Store pesticides in a place that can be locked and is not accessible to unauthorized people or children (Fig. 10.3); they should never be kept in a place where they might be mistaken for food or drink. Keep them dry but away from fires and out of direct sunlight. Do not carry them in a vehicle that is also used to transport food.

Disposal

Left-over insecticide suspension can be disposed of safely by pouring it into a specially dug hole in the ground or a pit latrine (Fig. 10.4). It should not be disposed of where it may enter water used for drinking or washing, fish ponds or rivers. Some insecticides, such as the pyrethroids, are very toxic to fish. Dig a hole at least 100 metres away from streams, wells and houses. In a hilly area the hole should be on the lower side of such areas. Pour run-off water from hand washings and spray washings into the hole, and bury containers, boxes and bottles used for pesticides in it (Fig. 10.5). Close the hole as soon as possible. Cardboard, paper and cleaned plastic containers can be burned (Fig. 10.6), where this is permitted, far away from houses and sources of drinking-water. For reuse of cleaned containers, see box (p. 388). Pyrethroid suspensions can be poured on to dry ground where they are quickly absorbed and degraded and do not cause environmental problems.

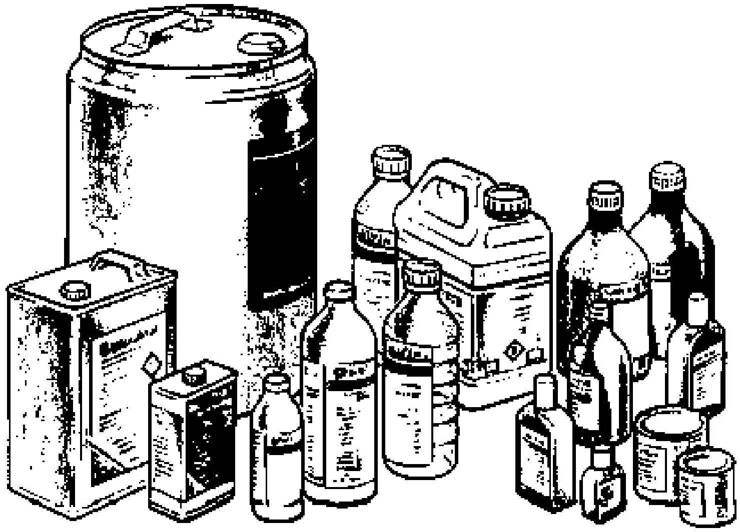

Fig. 10.1 Types of pesticide container (adapted from *2*).

WHO 96851

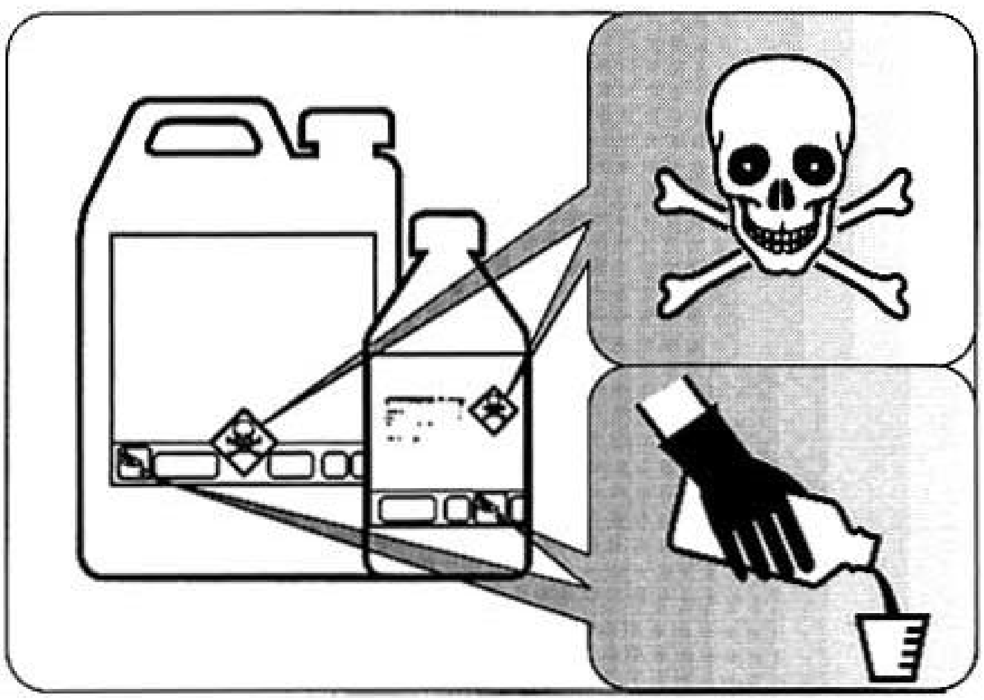

Fig. 10.2 Look for warning symbols, pictograms and colour coding on labels (adapted from *2*).

WHO 96852

Surplus solution can be used to kill insect pests such as ants and cockroaches. Pour or sponge it on to infested places (under kitchen sinks, in corners of a house). Insect breeding can be temporarily reduced by pouring the solution in and around latrines or similar breeding places. Solutions of pyrethroids for the treatment of mosquito nets and other fabrics can be used for a few days after preparation. The solution may also be used to treat sleeping mats or string mattresses to prevent mosquitos from biting from below. Where bedbugs are a problem, mattresses can be treated.

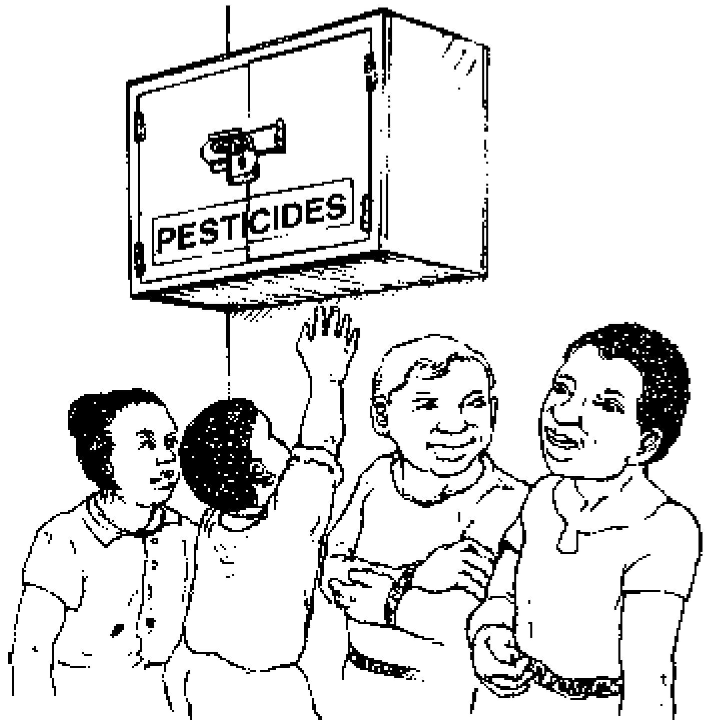

Fig. 10.3 Keep pesticides out of reach of children (adapted from *3*).

WHO 96853

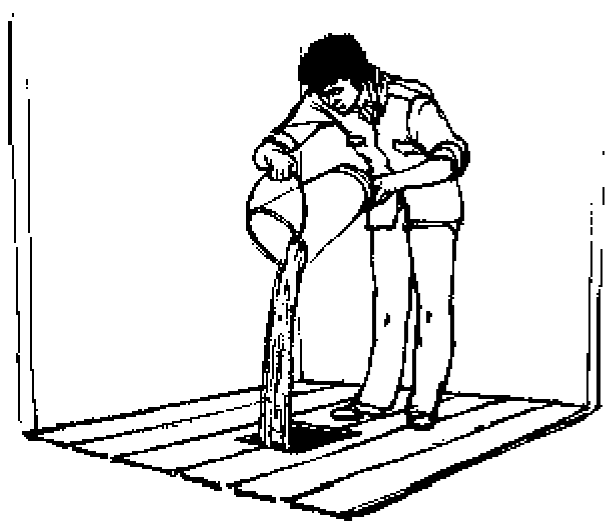

Fig. 10.4 Surplus insecticide solution can be disposed of safely by pouring it into a pit latrine or a specially dug hole in the ground.

Fig. 10.5 Packages to be buried must be made unusable and reduced in bulk as much as possible (adapted from *4*).

WHO 96854

Fig. 10.6 Clean paper and cardboard and cleaned plastic containers (not PVC) may be burnt (adapted from *4*).

WHO 96854

Cleaning used pesticide containers

The reuse of pesticide containers is risky and not recommended. However, some pesticide containers may be considered too valuable to be thrown away after use. Whether containers are suitable for cleaning and reuse depends on the material they are made of and what they contained. The label should provide instructions on possibilities for reuse and cleaning procedures.

Containers that have held pesticide formulations classified as highly hazardous or extremely hazardous must not be reused. Under certain conditions, containers of pesticide formulations classified as slightly hazardous or unlikely to present acute hazard in normal use can be reused for purposes other than the storage of food, drink or animal feed. Containers made of materials such as polyethylene that preferentially absorb pesticide should not be reused if they have held pesticides in which the active ingredient is classified as moderately, highly or extremely hazardous, regardless of the formulation.

Pesticide containers should be rinsed as soon as they are empty, completely filled with water, and allowed to stand for 24 hours. They should then be emptied, and the process repeated twice.

General hygiene

Do not eat, drink or smoke while using insecticides. Keep food in tightly closed boxes. Use suitable equipment for measuring out, mixing and transferring insecticides (Fig. 10.7). Do not stir liquids or scoop pesticide with bare hands. Use the pressure-release valve of the pump or a soft probe to clear blockages in the nozzle (Fig. 10.8; see also Chapter 9, p. 379). Wash the hands and face with soap and water each time the pump has been refilled. Eat and drink only after washing the hands and face (Fig. 10.9). Take a shower or bath at the end of the day.

Fig. 10.7 Use suitable equipment for measuring out and mixing insecticides (adapted from *2*).

WHO 96856

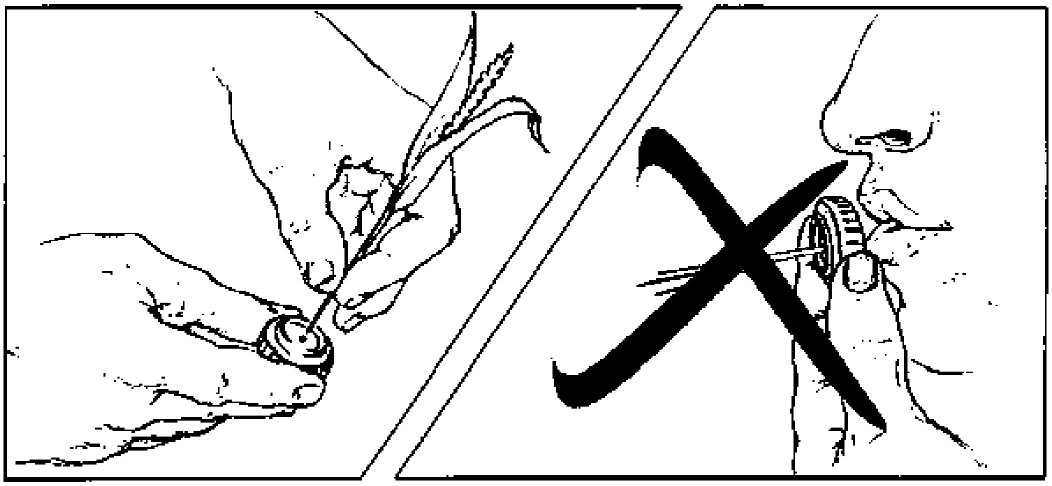

Fig. 10.8 Clean blocked nozzles with a soft probe (adapted from *2*).

WHO 96857

Protective clothing

Spraying indoors

Spray workers should wear overalls or shirts with long sleeves and trousers, a broad-brimmed hat, a turban or other headgear and sturdy shoes or boots. Sandals are unsuitable. The mouth and nose should be covered with a simple device such as a disposable paper mask, a surgical-type disposable or washable mask, or any clean piece of cotton. The cotton should be changed if it becomes wet. The clothing should be of cotton for ease of washing and drying. It should cover the body without leaving any openings. In hot and humid climates the wearing of additional protective clothing may be uncomfortable, and pesticides should therefore be applied during the cooler hours of the day.

Mixing

People who mix and pack insecticides in bags must take special precautions (see Chapter 9, p. 373). In addition to the protective clothing described above, it is recommended that gloves, an apron and eye protection such as a face shield or goggles be worn (Figs. 10.10 and 10.11). Face shields provide protection for the whole face and are cooler to wear. The mouth and nose should be covered, as recommended for indoor spraying. Care should be taken not to touch any part of the body with gloves while handling pesticides.

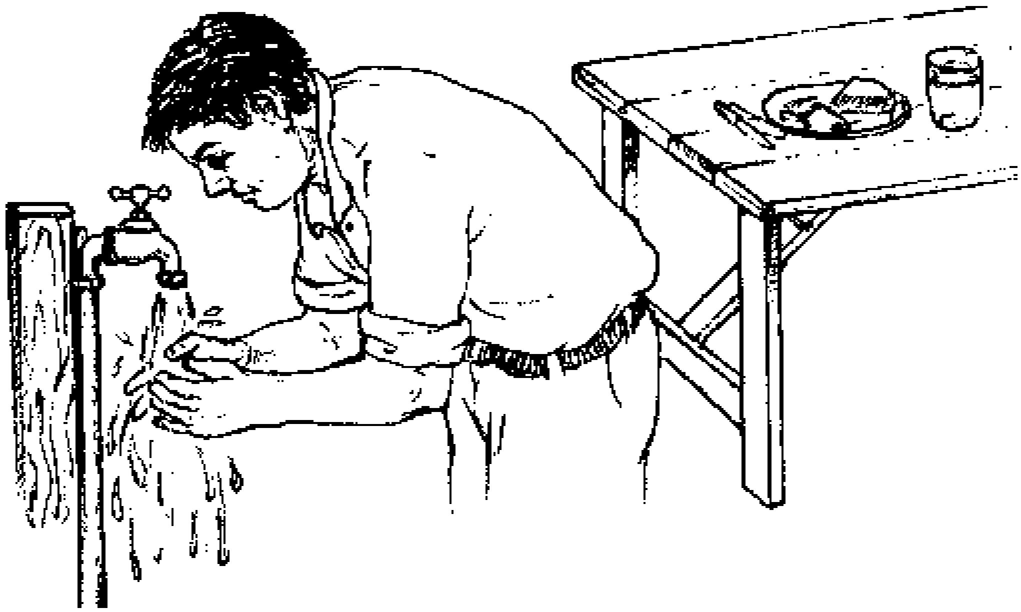

Fig. 10.9 Wash the hands and face before eating or drinking (adapted from *2*).

WHO 96858

Fig. 10.10 Wear gloves when handling concentrates.

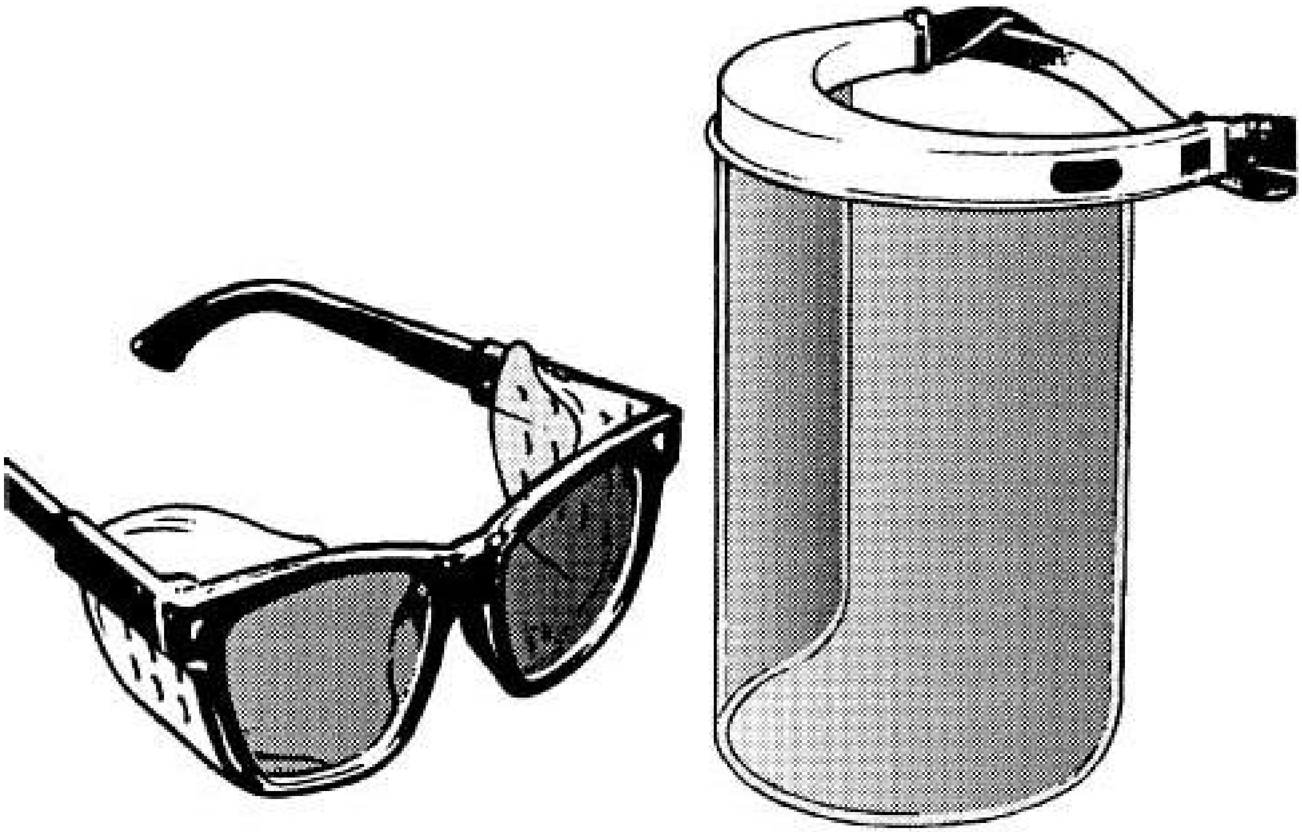

Fig. 10.11 Protective equipment for the eyes and face (adapted from *2*).

WHO 96859

Impregnation of fabrics

Long rubber gloves should be worn when treating mosquito nets, clothes, screening or tsetse traps with insecticides.

Under certain circumstances extra protection may be required, e.g. from vapour, dust or spray of hazardous products. Such additional protective items should be indicated on the product label and may include aprons, boots, face masks, overalls and hats.

Maintenance

Clothing should be kept in a good state of repair and should be inspected regularly for tears or worn areas through which skin contamination might occur. Protective clothing and equipment should be washed daily with soap, separately from other clothing. Gloves need special attention and should be replaced when there is any sign of wear and tear. After use, gloves should be rinsed with water before they are taken off. At the end of each working day they should be washed inside and outside.

Safe techniques

Spraying

The discharge from the sprayer should be directed away from the body. Leaking equipment should be repaired and the skin should be washed after any accidental contamination. Persons and domestic animals must not remain indoors during spraying. Rooms must not be sprayed if someone, e.g. a sick person, cannot be moved out. Cooking utensils, food and drinking-water containers should be put outdoors before spraying. Alternatively, they can be placed in the centre of a room and covered with a plastic sheet (Fig. 10.12). Hammocks, paintings and pictures must not be sprayed. If furniture has to be sprayed on the lower side and the side next to a wall, care should be taken to ensure that other surfaces are not left unsprayed. Floors should be swept clean or washed after spraying. Inhabitants should avoid contact with the walls. Clothes and equipment should be washed daily.

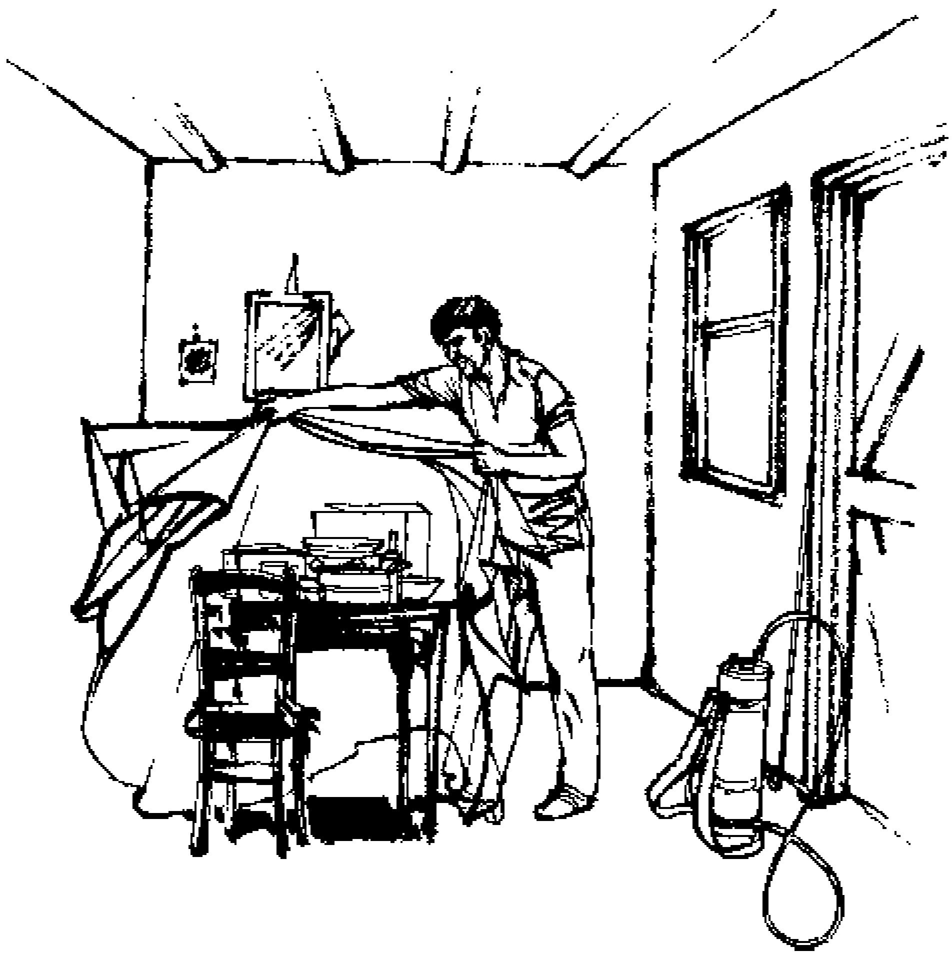

Fig. 10.12 Furniture and food should be covered with a plastic sheet or placed outdoors before a house is sprayed.

Organophosphorus and carbamate compounds should not be applied for more than 5 - 6 hours a day and the hands should be washed after every pump charge. Blood cholinesterase activity of spray personnel should be checked weekly if fenitrothion or old stocks of malathion are used (see box).

Monitoring exposure to organophosphorus compounds

Commercial field kits are available for monitoring blood cholinesterase activity. Low levels suggest overexposure to an organophosphorus insecticide. Such assays should be performed weekly for all persons handling these products. Persons with unduly low cholinesterase activity should stop working with insecticides until it has returned to normal.

Impregnation of fabrics

Gloves should be worn when handling the insecticide concentrate and preparing the insecticide mixture. Care should be taken to avoid splashing insecticide into the eyes. A wide, shallow bowl should be used (Fig. 10.13), and the room should be well-ventilated to avoid fumes being inhaled.

Fig. 10.13 Wear long rubber gloves and use a wide, shallow bowl when impregnating fabrics.

Emergency measures

Signs and symptoms of poisoning

Poisonings due to pesticides are usually acute and result from extensive skin contact or ingestion. Signs and symptoms vary with the type of pesticide and can sometimes be confused with those of other illnesses.

Indications of pesticide poisoning

General: extreme weakness and fatigue.

Skin: irritation, burning sensation, excessive sweating, staining.

Eyes: itching, burning sensation, watering, difficult or blurred vision, narrowed or widened pupils.

Digestive system: burning sensation in mouth and throat, excessive salivation, nausea, vomiting, abdominal pain, diarrhoea.

Nervous system: headaches, dizziness, confusion, restlessness, muscle twitching, staggering gait, slurred speech, fits, unconsciousness.

Respiratory system: cough, chest pain and tightness, difficulty with breathing, wheezing.

It is important to obtain additional information:

- Has the patient been working with a pesticide?
- Did contamination occur?
- Precisely which product was used?
- How much was ingested?
- How long ago?

An effort should be made to obtain evidence from pesticide containers or spray equipment; the labels on containers should be read and retained.

If pesticide poisoning is suspected, first aid must be given immediately and medical advice and help must be sought at the earliest opportunity. If possible, the patient should be taken to the nearest medical facility.

First-aid treatment

If breathing has stopped: Give artificial respiration. If no insecticide has been swallowed, mouth-to-mouth resuscitation may be given. Pull the patient's chin up and tilt the head back with one hand to keep the airway clear. Place the other hand on the patient's forehead, with the thumb and index finger toward the nose. Pinch together the patient's nostrils with the thumb and index finger to prevent air from escaping. Take a deep breath, then form a tight seal with your mouth over and around the patient's mouth (Fig. 10.14). Blow four quick, full breaths in first without allowing the lungs to deflate fully. Watch the patient's chest while inflating the lungs. If adequate respiration is taking place, the chest should rise and fall. Remove your mouth and allow the patient to breathe out (Fig. 10.15). Take another deep breath, form a tight seal around the patient's mouth, and blow into the mouth again. Repeat this procedure 10 - 12 times a minute (once every five seconds).

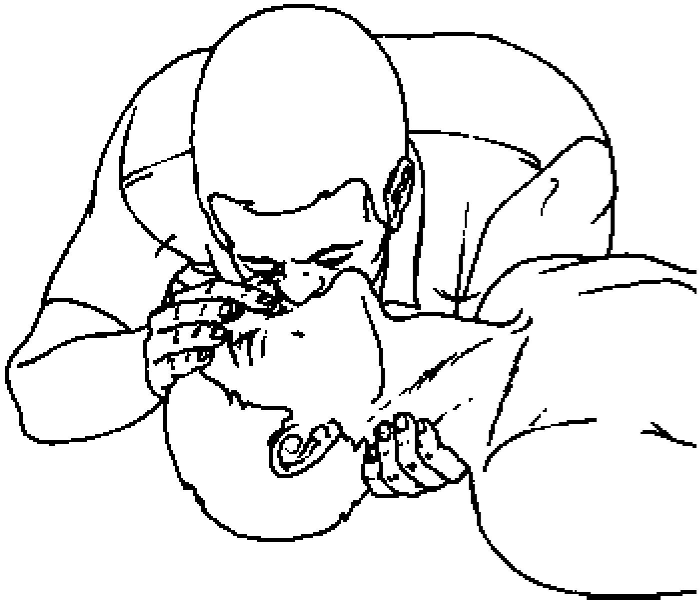

Fig. 10.14 Mouth-to-mouth resuscitation. Take a deep breath, then form a tight seal with your mouth over and around the patient's mouth (© WHO).

WHO 96860

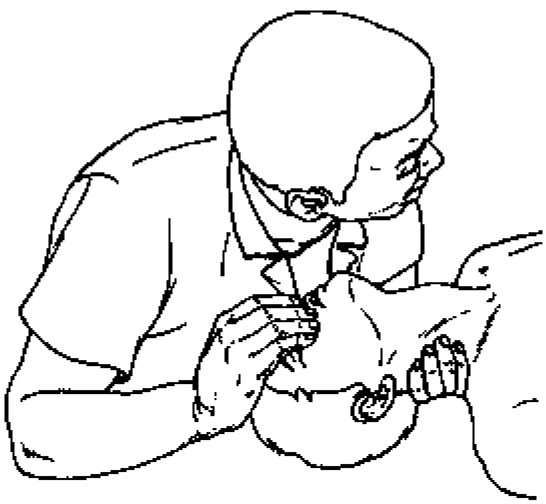

Fig. 10.15 Mouth-to-mouth resuscitation. Remove your mouth and allow the patient to breathe out (© WHO).

WHO 96502

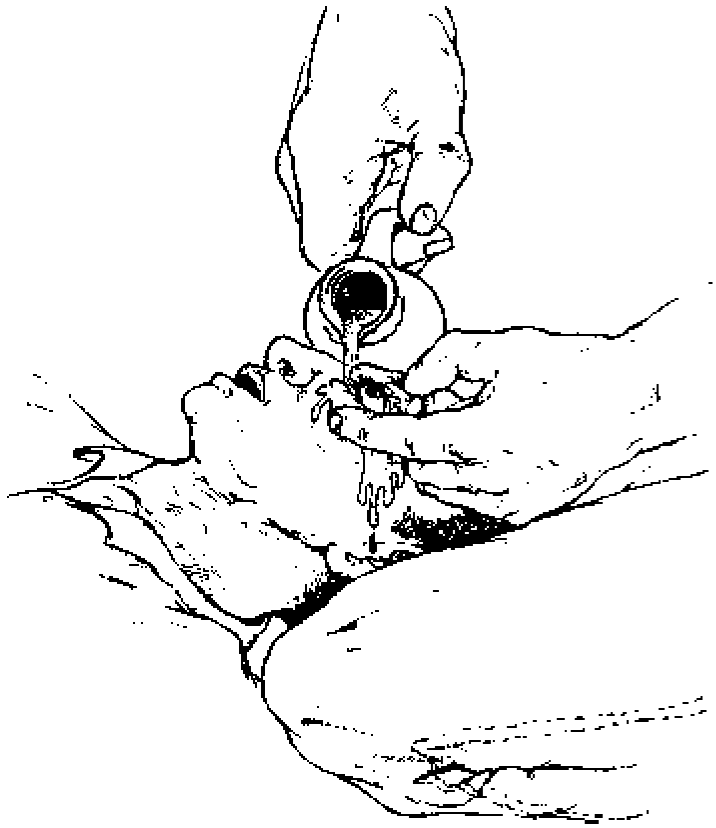

Fig. 10.16 Wash pesticide splashes from the eyes with clean water for at least five minutes (adapted from *3*).

WHO 96861

Artificial respiration should be continued for as long as possible if there is still a pulse. If insecticide has been swallowed, another form of artificial ventilation should be used.

If there is insecticide on the skin or in the eyes: Rinse the eyes with large quantities of clean water for at least five minutes (Fig. 10.16). Remove contaminated clothing from the patient and remove the patient from the contaminated area (Fig. 10.17).

Wash the body completely for at least 10 minutes, using soap if possible. If no water is available, wipe the skin gently with cloths or paper to soak up the pesticide. Avoid harsh rubbing or scrubbing.

Vomiting

Do not induce vomiting unless the patient has swallowed pesticide that is known to be highly toxic, and medical help is not expected soon. Never induce vomiting if the patient has swallowed oil spray or products diluted in diesel or kerosene, because of the possibility of inhalation of the vomited material, which would be more dangerous than the intestinal poisoning. The product label should indicate whether the pesticide is highly toxic (skull-and-crossbones signs). Vomiting should be induced only if the patient is conscious. If necessary, sit or stand the person up and tickle the back of the throat with a finger. Whether vomiting occurs or not, give the patient a drink comprising three tablespoonfuls of activated charcoal in half a glass of water. Repeat until medical help arrives.

Caring for the patient

Make the patient lie down and rest because poisoning with organophosphorus and carbamate compounds is made worse by movement. Place the patient on her or his side with the head lower than the body. If the patient is unconscious, pull the chin forward and the head back to ensure a clear airway (Fig. 10.18). Cover the patient with a blanket if he or she feels cold, and cool the patient by sponging with cold water if excessive sweating occurs. If the patient vomits spontaneously, ensure that he or she does not inhale the vomit. In the event of convulsions, put padded material between the teeth to avoid injury.

Fig. 10.17 Remove contaminated clothing immediately and wash the skin (adapted from *3*).

WHO 96862

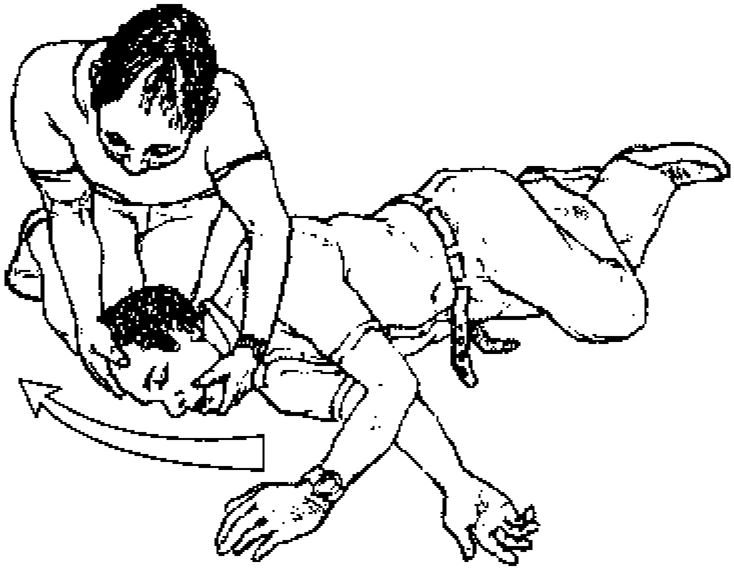

Fig. 10.18 Place an unconscious patient on her or his side and tilt the head back (adapted from *5*).

WHO 96863

Do not allow patients to smoke or drink alcohol. Do not give milk. Water can be given.

Further treatment

Patients requiring further medical treatment should be referred to the nearest medical facility. Detailed guidelines for the management of poisoning are being prepared by WHO (*6*). A list of poisons information centres is also available on request (*7*).

References

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Selected further reading

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International Programme on Chemical Safety. *The WHO recommended classification of pesticides by hazard and guidelines to classification 1994 - 1995*. Geneva, World Health Organization, 1994 (unpublished document WHO/PCS/94.2; available on request from Programme for the Promotion of Chemical Safety, World Health Organization, 1211 Geneva 27, Switzerland).

Safe use of pesticides. Fourteenth report of the WHO Expert Committee on Vector Biology and Control. Geneva, World Health Organization, 1990 (WHO Technical Report Series, No. 813).

Selected WHO publications of related interest

Vector control for malaria and other mosquito-borne diseases.
Report of a WHO Study Group.
WHO Technical Report Series, No. 857 • 1995 • 97 pages
Sw. fr. 15. -

Lymphatic filariasis: the disease and its control.
Fifth report of the WHO Expert Committee on Filariasis.
WHO Technical Report Series, No. 821 • 1992 • 77 pages.
Sw. fr. 10. -

Entomological field techniques for malaria control.
Part I: Learner's Guide.
1992 • 77 pages.
Sw. fr. 15. -

Part II: Tutor's Guide.
1992 • 54 pages.
Sw. fr. 12. -

Vector control in primary health care.
Report of a WHO Scientific Group.
WHO Technical Report Series, No. 755 • 1987 • 61 pages
Sw. fr. 9. -

Equipment for vector control.
3rd edition • 1990 • x + 310 pages
Sw. fr. 51. -

Further information on these and other WHO publications can be obtained from Distribution and Sales, World Health Organization, 1211 Geneva 27, Switzerland

Prices in developing countries are 70% of those listed here.

Back cover

Diseases transmitted by arthropods and freshwater snails are among the most common causes of illness and premature death in tropical and subtropical countries and, to a lesser extent, in temperate zones also. In addition to their direct effects on health, such diseases - which include malaria, filariasis, leishmaniasis, schistosomiasis, dengue and trypanosomiasis - hinder economic development, as a result of lost working hours and the high costs of treating those affected and of vector control.

Large-scale campaigns for vector control are often unworkable for both financial and practical reasons, as well as being potentially damaging to the environment. For these reasons, attention has shifted to methods that can be applied by individuals and communities. This manual provides practical information on methods that are suitable for self-protection by families and communities in both rural and urban areas and that require only limited involvement by health services. In general these methods are relatively simple and cheap, do not require much training and, if properly applied, are safe for the user and the environment.

The manual provides practical information on all major disease vectors and pests: mosquitos and other biting Diptera, tsetse flies, triatomine bugs, bedbugs, fleas, lice, ticks, mites, cockroaches, house-flies, water fleas and freshwater snails. For each group of vectors, information is provided on biology, public health importance and control measures. Chapters on house-spraying with residual insecticides and the safe use of pesticides are also included.

This manual is principally intended for health workers and auxiliary staff working with people at district and community level, as well as for health planners, aid organizations and those working in refugee camps.